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IMPROVED SEALANTS FOR INFILTRATION CONTROL. THE DEVELOPMENT AND DEMONSTRATION OF MATERIALS TO REDUCE OR ELIMINATE WATER INFILTRATION INTO SEWERAGE

Western Company
Richardson, Texas

June 1969

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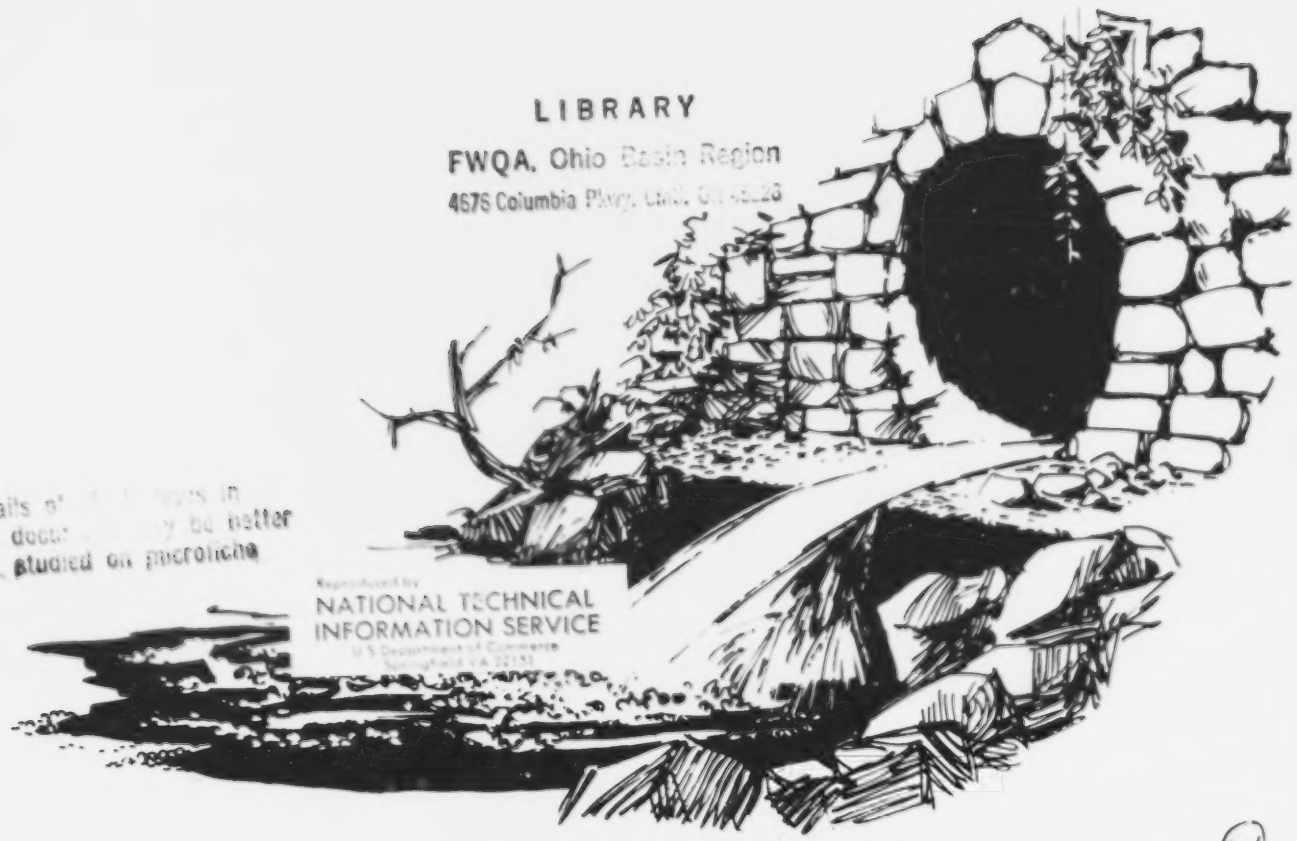

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ERRATA

Page 16. Under System A_2 in Table I: Base B_1 should read Base B; System B should read System B_1.

Page 21. Last Paragraph, last sentence: simce should read since.

Page 37. Under Viscosity in Table IX: column labeled Sealant should be labeled Static.

Page 44. Duplication copy, delete entire page.

Page 63. First sentence: equigalent should read equivalent.

Improved Sealants for Infiltration Control

THE DEVELOPMENT AND DEMONSTRATION OF MATERIALS TO REDUCE OR ELIMINATE WATER INFILTRATION INTO SEWERAGE

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

by

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2201 N. Waterview Parkway
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Program No. 11020 DIH
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June, 1969

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ABSTRACT

The objective of this program was to develop new, more effective sealants for sewer line leaks (leaking joints, cracks and large holes). This purpose was achieved, and all equipments and materials investigated, tested or compared are presented, along with test results, supporting data, conclusions and recommendations. A wide range of candidate materials was surveyed, and weaknesses of rejected materials were noted. Meanwhile, specific properties of acceptable materials were ascertained and materials having these properties were identified. These latter materials were subjected to tests designed to demonstrate their effectiveness as sealants. Cost/effectiveness of the new sealant materials was compared with that of present sealant materials. It was concluded that infiltration adversely influences sewer system operating costs and effectiveness, and that leakage repair systems are limited in their effectiveness. Several sealants developed during the program were demonstrated to be able to effect strong, permanent repairs. No significant cost increase beyond that experience with present sealers was indicated. Some present sealant application equipment can be modified for use with the new materials, but new equipment designs are described and recommended. Too, long-term field tests of the materials are recommended.

This report is submitted in fulfillment of Contract 14-12-146, between the Federal Water Pollution Control Administration and The Western Company of North America.

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SECTION I

CONCLUSIONS

1. Excessive infiltration into sewer lines displaces valuable sewer capacity, increases collection system maintenance costs, increases sewer plant operating costs and increases the pollution in our streams and waterways.

2. A chemical blocking method employing acrylamid gels is currently being used to seal leaking sewers with its success limited by the sealant's lack of strength and other physical limitations.

3. Four epoxy-based sealants and two urethane-based sealants developed in the reported program can result in strong, permanent repairs.

4. The new sealants are suitable in conditions of erratic infiltration where the acrylamid gels fail due to repeated dehydration.

5. Equipment for applying the new sealants can be designed to cost about the same as existing equipment; however, existing equipment for applying sealant can be modified to accept the new sealants.

6. The new sealants do not significantly increase the cost of sealing sewers since the major cost of sealing leaks is in the mechanics of finding and sealing them, not in the cost of the sealants used.

SECTION II

RECOMMENDATIONS

This program was limited to the laboratory study and development, and scaled-up testing, as described elsewhere in this report. It was not within the scope of the program to fully develop the new sealants through full-scale, long-term testing in sewers or under the exact chemical, biological or physical conditions existent in sewers. It is recommended, however, that such field testing be carried out.

In such a program, specially designed equipment recommended and generally described elsewhere in this report should be designed and fabricated, utilized in the testing, and evaluated and redesigned as needed.

Testing of the new sealants, implaced by the newly developed equipment in actual sewers, would permit long-term evaluation of repairs made, and a program to incorporate such testing is recommended.

It should be noted, however, that by utilizing existent equipment, properly modified, the new sealants can be used now, and their use is recommended when 1) strength is needed to hold against high head pressures, 2) flexibility is needed to allow for shifting soils, 3) wide spaces or gaps need to be bridged, and 4) when ambient external conditions alternate frequently between wet and dry. It is suggested, however, that the new sealants be applied only under conditions of low or no infiltration until further testing can determine the effects of inflow on the sealing and curing process.

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SECTION III

INTRODUCTION

A. PROBLEM BACKGROUND

Ground-water infiltration into sanitary sewerage causes an enormous burden to be placed on many communities (Reference 1), measured in terms of 1) pollution of waterways (caused by raw sewage being inadequately treated due to hydraulic overload on the sewage treatment plant), 2) large increases in operating and capital investment costs to handle fluid flow, and 3) health hazards when infiltration flow blocks and backs up sanitary sewage flow.

Reference 1 further states that in a typical town the average sewage flow was three times the average water used. In another example, a town with a relatively modern separated sewer system had yearly operating costs (just to process infiltration water) of $105,862, or 32.1 percent of the budget of $329,787 went to process infiltration water (Reference 4). This annual expense includes plant operation, plant construction debt retirement and interest charges, but does not include maintenance of the collection system.

The millions of miles of sewers presently in the ground in all states in the United States contain an enormous number of leaks caused by cracks, breaks and loose joints. These leaks allow a tremendous amount of ground water to flow into the sewerage (Figure 1). This excessive accidental flow of fluid into the system produces many undesirable effects:

Increased hydraulic load on treatment plants are caused by infiltration. This additional load often means sanitary sewage is either inadequately treated or not treated at all because it either bypasses the treatment plant or passes through too rapidly and is passed into a waterway, polluting it (Reference 1).

Increased sewage-treatment-plant operating costs are incurred in handling the infiltrated fluids.

More capital investment is required to lay the larger sewers required to handle the infiltration flow. Reference 1 points out that sanitary sewers are designed three to five times larger than normal flow requirements to allow for infiltration. Also, treatment plants must be overdesigned. This over-design increases initial cost of sewer systems by a significant amount.

Increased load on sewerage caused by infiltration often results in overflow and backup in a system. Backup often causes considerable property damage and personal inconvenience, and poses a severe health hazard (Reference 1).

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Infiltration in the sewer system of a growing community can cause the system to become inadequate much sooner than planned, which leads to more capital investment to increase the sewer's capacity sooner than would otherwise be needed, if ever.

Fluid filtrating into sewerage often brings with it sand, silt and other materials that eventually block the sewer, requiring extensive maintenance expenditure.

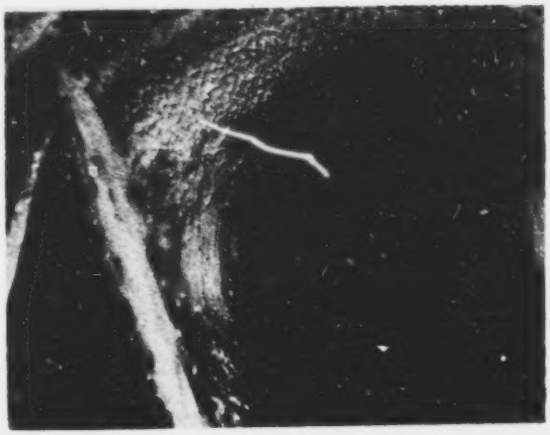

Figure 1. Water Infiltrating into Damaged Sewer Pipe.

Reference 2 notes that the causes for cracks, breaks and bad joints in a sewer are numerous, suggesting a need for more than one type of solution. Listed below are major causes of pipe failure which can result in infiltration:

- Poor or improperly made joints.
- Inadequate bedding or foundation.
- Improper backfill.
- Shear of pipe when traversing from a firm soil to a yielding soil.
- Improper connection of house lateral to main collecting system.
- Inadequate material used for house laterals.
- Poor construction and inspection of house laterals.
- Blown joints or bursted pipes due to internal pressure.
- Pipe corrosion.

Reference 3 states that excessive infiltration in both wet and dry periods occurs in every major U. S. river basin, often exceeding design standards and code regulations. This reference defines infiltration as "ground water which leaks or seeps into a sewer through defective joints, ruptured or porous pipes or manholes or other sewer system appurtenances."

Until the Federal Water Pollution Control Administration recently initiated action in this area, infiltration was generally looked upon as an acceptable evil. Even now, in cases where leaks into a sewer reach an emergency condition, pipe is either removed and replaced or a hole is drilled in the earth down to the pipe and the cavity around the sewer is flooded with concrete. Replacing pipe is an excellent method of stopping infiltration at a point, but is much too expensive (costs averaged approximately $2.25 per foot for a large section of 8-inch pipe to be replaced in 1964, and this cost has continued to increase).

The second method (flooding a cavity around the pipe with concrete) is somewhat less expensive; however, its success is not noteworthy because concrete does not necessarily go into the places where it is needed. In addition, sealing a crack on the bottom is extremely difficult due to inability to properly place the concrete. Also, for large holes or broken sections, concrete often flows through the opening and down into the sewer, thus sealing the wrong portions of the line.

Recently, chemical blocking techniques have been used to block infiltration in sewers in Florida, Louisiana and other areas where the water table is up to or higher than the sewer. Here, a water-soluble chemical (acrylamid) and a water-soluble catalyst are pumped into the sewer under pressure and forced out through cracks or openings. The chemical examination of this type of polymer, in the light of the stringent requirements for a good solution to the infiltration problem, reveals the following weaknesses:

- The polymer does not bond pipe segments together to provide structurally sound pipe.
- The polymer generally does not seal large holes.
- Repeated cycles of wet-to-dry-to-wet conditions reduces the effect of the seal.

B. PROBLEM DEFINITION

With the preceding background in mind, the problem definition is developed in terms of typical leaks to be dealt with in reducing or eliminating infiltration, and the type of service required by the repair.

Types of failures which must be sealed include 1) leaking joints, 2) cracks and 3) large holes in the sewer.

To provide a seal that is economically worthwhile, the seal must have the following properties:

- Permanence (i.e., it should be expected to last the economic life of the pipe or be inexpensive enough to warrant repeated application).
- Bonding ability (i.e., bond edges of pipe break together).

- High structural strength.
- Bridging ability (i.e., bridge over holes and gaps).
- Adaptability (i.e., withstand climatic extremes).

C. PROJECT OBJECTIVES

Analysis of the problem revealed the need for development of materials for chemical blocking that can seal, bond, carry structural load, bridge gaps, and be implaced from the inside of a sewer (with appropriate equipment).

Objectives of the program were to:

- Survey a wide range of materials.
- Point out weaknesses of rejected materials.
- Ascertain specific properties expected to selected materials.
- Identify materials possessing desired properties.
- Demonstrate methods of modifying nearly acceptable materials to make them acceptable.
- Demonstrate effectiveness of new and improved sealants developed under this program.
- Investigate and evaluate existing equipment for applying new sealants in the field.

SECTION IV

TECHNICAL DISCUSSION

A. LITERATURE SURVEY

1. Scope of Survey

Suggestions for products to use as sewer repairing materials were taken from periodicals such as Chemical Abstracts, Engineering Index, Water and Waste Engineering, Public Works, Environmental Science, Industrial and Engineering Chemistry, Chemical Engineering, Chemical Engineering Progress, Modern Plastics, and the Water Pollution Control Federation Journal and from such other sources as raw material manufactures' literature, commercial sewer sealer operators' comments, consumer products manufacturers' literature, and clay pipe manufacturers' and consultants' comments. The Western Company and company experience were also gleaned.

Results obtained from the literature survey (see Appendix I) showed that the most promising sources of material for sealing a leaking sewer came from technologies such as pipe sealing, soil stabilization, adhesives, petroleum formation plugs, water formation plugs, and other sealing operations involving tile, concrete and plastics.

2. Basis of Survey

The objective of the literature survey was to locate materials with high tensile or flexural strength, appropriate set time, appropriate application properties, good water resistance, and sewage resistance.

Companies in associated fields were contacted and solicited for the type of material being sought.

3. Selection of Materials

Of the 170 companies solicited, 54 responded with positive answers and product literature for further screening. Samples were obtained from the following companies:

(Epoxies)

- Ciba
- Tra-Con
- Epoxylite
- Adhesives Products Corp.
- Miller-Stephenson Chemical Co.
- Aba Products Co.
- Marblette
- Enjay Chemical Company
- Matcote Company, Inc.
- Amercoat Corp.

Dow Chemical
Shell Chemical
Union Carbide

(Urethanes)
Poly Resins
Conap Inc.
W. S. Dickey
Spencer-Kellogg
Baker Castor Oil Co.

(Polyesters)
Ashland Chemical
Pittsburg Plate Glass Co.
Dow Chemical

(Miscellaneous)
Paisley Products
Oil Center Research
Pennsalt Agricultural Chemicals
Witco
Eastman Chemical Products
Thiokol
Firestone
Hooker Chemical Corp.
Syntar
Byereyte Co.
B. F. Goodrich

After samples were received, any candidates obviously lacking in any of the properties listed above (Basis of Survey) according to the manufacturer's accompanying literature were discontinued from testing unless modifications could improve the failing properties.

B. LABORATORY TESTING OF MATERIALS

The materials selected as a result of the literature survey were subjected to laboratory tests designed to best provide a medium for comparison of candidate materials, and to best simulate conditions encountered by the sealants. Unglazed ceramic tiles (2" x 2" x 1/4") were used as test specimens to be bonded together by the sealant. These tiles were cleaned in a detergent solution, rinsed thoroughly and allowed to dry prior to application of the sealant.

To first examine the feasibility of using this type of tile, a correlation study was made. An epoxy and a urethane sealant were first tested using ceramic tiles and then by using clay tiles. The tensile strengths measured by bonding ceramic-tiles were correlated to those strengths measured using clay-tiles. The clay tiles were of identical material to

sewer pipes. In the case of the epoxies, values from clay tiles were 25.5 percent higher than those from ceramic tiles. In the case of the urethanes, values from ceramic tiles were 15.8 percent higher than those from clay tiles (see Appendix II).

Cement blocks were examined also. The majority of cases showed that for any material exhibiting a tensile strength greater than 199 pounds per square inch or a flexural strength greater than 699 pounds per square inch, the concrete would break (rather than cause the bonding material to delaminate or fail).

Thus, the ceramic tiles provided a means for testing materials with higher strengths, since they were structurally stronger than clay or cement tiles.

Test samples were prepared by applying the sealant along one of the 1/4-inch edges of each of two tiles. The two coated edges of the tiles were butted together (Figure 2) and the tiles were placed on flat polyethylene sheets and allowed to air cure at 75°F for a minimum of 24 hours before testing or conditioning.

Ten samples of each candidate sealant were prepared, five of which were tested under dry conditions. The remaining five were placed in a circulating water bath, controlled to 75°F, and allowed to remain for five days before testing.

Sealants with good performance on clean, wet tiles were also tested on tiles soaked for a minimum of one month in a synthetic sewage made of the following ingredients:

12.0 g dextrose.
180.0 mg L M potassium phosphate.
6.0 g ammonium sulfate.
2.4 g magnesium sulfate.
240.0 mg manganese sulfate.
180.0 mg calcium chloride.
12.0 mg ferric chloride.
5.0 ml SAE 30 motor oil.
Tap Water to 12 liters.
50.0 cc of 5 percent algae in 300 ppm AP-30 solution.

Sealants tested under these conditions are noted in Appendix III.

After conditioning, the bonded tiles were tested by using a Dillon Model LW Tester (Figure 3). For flexural testing, the loading rate was never to exceed $N = 0.107d$ per minute, where N is the number of turns and d is the depth of the tile. For tensile testing, the loading rate range was adjusted from 2,400 to 2,800 psi per minute.

Figure 2. Specimen Tiles Bonded Together

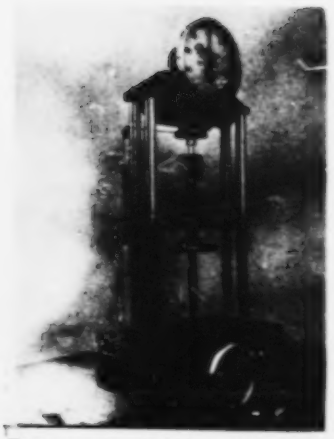

Figure 3. Dillon Tester

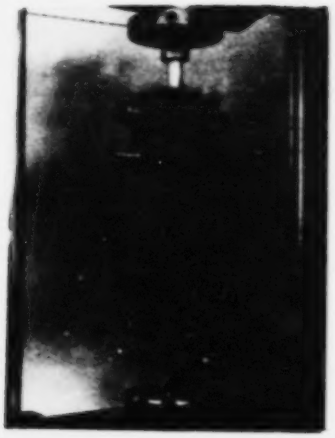

Figure 4. Flexural Testing of Bonded Tiles.

To measure flexural strength, the bonded tiles were placed in the Dillon Tester (Figure 4). (Precautions were taken to center the bond.) The following calculation was then made:

$$S = \frac{3\,PL}{4\,bd}$$

where

S = flexural strength (lb/in^2).
P = gauge reading in pounds.
b = width of joint.
d = depth of joint.
L = distance between tester supports.

Type of failure was recorded as 1) breaking, 2) buckling or 3) delamination.

Tensile strengths were measured by placing the bonded tiles in the Dillon Tester (Figure 5), and by calculating as follows:

$$T = \frac{P}{bd}$$

where

T = tensile strength (lb/in^2).
P = gauge reading in pounds at the breaking point.
b = width of joint in inches.
d = depth of joints in inches.

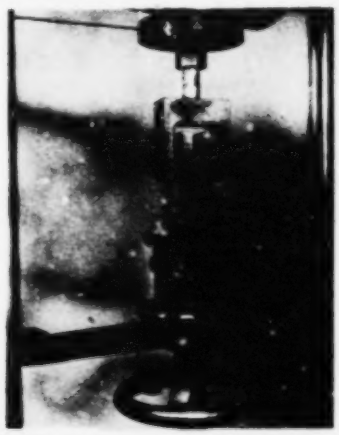

Figure 5. Tensile Testing of Bonded Tiles.

The type of failure was recorded as:

1) Percent cohesion failure = failure within the adhesive itself.

2) Percent contact failure = surface failure due to lack of adhesion wetting.

3) Percent adhesion failure = failure of the bond between the surface of the test specimen and the adhesive.

4) Percent adherent failure = failure where the adhesive actually breaks away part of the test specimen, the adhesive bond being stronger than the test specimen.

The modulus of elasticity was determined by the following (by using the same procedures as for flexural testing):

$$E = \frac{PL^3}{4\,Dbd^3}$$

where

E = modulus of elasticity.
D = deflection in inches of the middle of the sample (determined by the difference of movement between the lower and upper supports of the Dillon tester).

The viscosity was measured at 75°F and reported in centipoises. In the case of multicomponent systems, the viscosity reported is representative of the sealant after it was mixed and ready for application. Viscosities were measured (on a Brookfield Model LV viscosimeter by using appropriate speed and spindle), or the manufacturer's stated viscosity was listed when available.

In the application encountered in this project, the best sealants were found to be highly thixotropic or non-Newtonian in their flow properties. Many of the sealants were too thick or viscous to measure viscosity (noted in Appendix III as "paste" or "thixotropic") but, where possible the thixotropic effects were reported by the thixotropic index, determined on the Brookfield viscosimeter:

$$\text{Thixotropic Index} = \frac{\text{Viscosity at 2 rpm}}{\text{Viscosity at 20 rpm}}.$$

The set time was measured as the time required for the sealant to become nontacky to the touch (ASTM-2471). In the case of exothermic reactions, the set time shortened considerably with larger volumes. The values reported on the charts are for 35 to 50 grams of material mixed at 75°F, unless otherwise stated. The set time is intended to give a relative indication of time required to cure, i.e., comparison between sealants tested. The wide variety of thermally conductive materials, in this case, sewer pipes and their environments, makes it impractical to attempt to record a set time applicable to every condition. In the large-scale testing where three to five pounds of material were used, the distribution of this material about the pipe, and the large contact area between the sealant and the pipe, conducted the heat of reaction away from the sealants, thus lengthening the set time. In all cases, if a laboratory set time of 30 minutes or less was reported, a thorough cure was established (during large-scale testing) between application of the sealant and disassembly of the test-application box some 24 hours later.

Peak exotherms were recorded on a Sargent Model SR strip recorder coupled to a chromel-alumel thermocouple. Specified amounts of the components were mixed at 75°F and placed in a nine-ounce paper cup on a nonconductive surface in still air. This procedure is described in ASTM D2471-66T.

Testing of the candidate sealants' resistances to sewage was conducted in the following manner. A specimen of the sealant was cured in a plastic breaker, then removed, weighed, and the volume measured by water displacement. The cured samples were soaked in the sewage system (described on page 9) for one month, then removed from the sewage, weighed and the volume measured. Initial test results (Appendix III Part F) were compared with raw material manufactueres' data and both showed chemical and water resistance of the epoxy and urethane type sealants to be more then adequate (Reference 9 (p. 6-46 to 48), 10, 11, 12, (p. 117 and 168) and 13 (p. 780, 783).

Values reported are mean values (average). Results that deviated from the mean value of all tests were rejected if the deviation of the doubtful value was more than five times the average deviation from the mean obtained by excluding the doubtful value (ASTM D-1184).

3. Materials Tested

All materials submitted during the survey, and of which samples were available, were subjected to the laboratory tests above unless some property of a material rendered it inapplicable under the conditions of the tests. Tests showed very early the superiority of the thixotropic type materials over the water-thin systems in sealing breaks of clay sewer pipes. This superiority, along with the exceptional strength demonstrated by the high molecular-weight type materials, shifted the attention of laboratory tests toward the thixotropic polymer systems. General classes of materials tested included:

Epoxy polyamide.
Epoxy polysulfide.
Urethane (two component).
Ricinoleate urethane.
Polyester.
Water-extended polyester.
Polyester urethane.
Poly olefin.
Vinyl ester.
Vinyl chloride.
Furfuryl alcohol resin.
Atactic polypropylene.
Acrylamid gel.
Gypsum cement.
Asphaltic emulsion.

4. Results of Testing

The laboratory study resulted in ten basic sealant systems. The formula breakdown is listed in Table I.

By using the methods and tests described above a systematic approach was taken to eliminate unsuitable candidates and to select those materials that would perform adequately. In the process, the affects of various conditions or modifications were determined. Appendix III contains all the information gained in the initial testing phase.

The inherent limitations of the various classes of materials (noted above) necessitated modifications before data of any value could be obtained. The data is presented in a categorized manner in Appendix III to permit study of the affects of various modifications. The categories used include:

TABLE I. Formula Breakdown of Sealant Systems Subjected to Large Scale Testing

Sealant	Amount (parts)	Constituent
System A_1		
Base A	100.0	DGEBA, W.P.E. = 205
	12.0	Butyl glycidyl ether
	5.6	Fumed silica
Base B	25.0	Araldite 956 (Modified amine. Amine value of 23.5 to 27.0)
System A_2		
Base A	100.0	DGEBA, W.P.E. 205
	6.0	Butyl Glycidyl ether
	7.0	Fumed silica
	1.4	Tween 80 (Polyoxyethylene (20) sorbitan monooleate)
Base B_1	25.0	Araldite 956 (Modified amine. Amine value of 23.5 to 27.0)
System B		
Base A	50.0	DGEBA, W.P.E. = 205
	50.0	DGEPG, W.P.E. = 175
	5.7	Fumed silica
Base B	17.0	Araldite 956 (Modified amine. Amine value of 23.5 to 27.0)
System B_2		
Base A	75.0	DGEBA, W.P.E. 205
	25.0	DGEPG, W.P.E. 175
	6.0	Fumed silica
Base B	21.0	Araldite 956 (Modified amine. Amine value of 23.5 to 27.0)
System D_1		
Base A	91.0	DCUE 1072-31 Part A (Polyether urethane - OH terminated)
	2.5	Fumed silica
	0.5	Tween 80 (Polyoxyethylene (20) sorbitan monooleate)
Base B	9.0	DCUE 1072-31 Part B (Isocyanate - Terminated prepolymer)

TABLE I. (Continued)

Sealant	Amount (parts)	Constituent
System D_2		
Base A	91.0	DCUE 1072-31 Part A (Polyether urethane - OH terminated)
	3.0	Fumed silica
	0.9	Polyoxyethylene (20) sorbitan monooleate
Base B	9.0	DCUE 1072-31 Part B (Isocyanate - Terminated prepolymer)
System E_1	(Low Viscosity)	
Base A	91.2	B-430 (Polyether urethane - OH terminated)
	1.7	Fumed silica
	0.42	Tween 80 (Polyethylene (20) sorbitan monooleate)
Base B	8.2	DCAD 1024-1 (Isocyanate - Terminated prepolymer)
System E_2	(Low Viscosity)	
Base A	91.2	B-430 (Polyether urethane - OH terminated)
	1.7	Fumed silica
	.93	Tween 80 (Polyethylene (20) sorbitan monooleate)
Base B	8.2	DCAD 1024-1 Isocyanate - Terminated prepolymer)
System F_1		
Base A	50.0	Matstick 24 (Pigmented epoxy - contained asbestos)
Base B	50.0	Matstick 25 (Polyamide catalyst)
System F_2		
Base A	47.5	Matstick 1-LD-1146"A" (Epoxy pigmented)
	2.5	Fumed silica - substituted for asbestos
Base B	50.0	Matstick 1-LD-1146 "B" (Polyamide catalyst)
System G_1		
Base A	96.0	Cital Aquacoat 2805T Base A (Epoxy Coating)
Base B	6.0	Cital Aquacoat 2805T Catalyst

TABLE I. (Continued)

Sealant	Amount (parts)	Constituent
System G_2		
Base A	96.0	Cital Aquacoat 2805 T - Base A (Epoxy-based coating)
	1.46	Fumed silica
Base B	6.0	Cital Aquacoat 2805T (Catalyst)
System H		
Base A	100.0	Selectron RS(5119 (Polyester resin containing 35 percent styrene monomers)
	4.5	Fumed silica
Base B	0.6	Lupersol 224 (MEK peroxide)
System I		
Base A	100.0	Nuklad 105 "A" (Epoxy-based primer)
	4.2	Fumed silica
	2.1	Glycerin
Base B	20.0	Nuclad 105 "B" (Epoxy catalyst)
System J		
Base A	100.0	WEP-27 (Unsaturated water-extended polyester)
	2.5	Cobalt napthenate
	.5	Dimethylaniline
	125.0	H_2O containing 400 ppm (by weight) hydroquinone
Base B	1.0	Lupersol DDM (MEK peroxide)
System K		
Base A	50.0	DGEBA, W.P.E. 205
	50.0	DGF°G, W.P.E. 425
	5.0	Fumed silica
Base B	13.0	Araldite 963 (Modified polyamide)

TABLE II. Properties of Systems Selected from Laboratory Testing

System No.	Viscosity (20 RPM)	Thixotropic Index	Specific Gravity	Peak Exotherm and Minutes to Read	Flex (psi)	Tensile (psi)	Modulus of Elasticity	Type Failure	Comments
A_1	42,200 cps #7 spindle thixotropic	8.10	1.18	238°C 22 min.	5560	1134	1.01×10^7	C	
F_2	37,000 cps #7 spindle thixotropic	5.60	1.24	146°C 50 min.	5549	1694	1.87×10^6	C	Very tacky.
G_2	23,000 cps #7 spindle thixotropic	5.85	1.68		3733	1136	2.02×10^6	C	Added fumed silica to enhance thixotropic properties.
I	154,800 cps #7 spindle thixotropic	7.45	1.11	119°C 50 min.	3194	1168	1.23×10^6	C	Slow-curing. DMP-30 will accelerate cure but destroy thixotropic properties.
H	32,200 cps	6.40	1.15	175°C 25 min.	2301	1052	1.12×10^7	A	Needs improved adhesion properties and is temperature sensitive.
D_1	50,400 cps	6.10	1.25	52°C 5 min.	317	352	1.04×10^4	C	Needs a phenolic-nitro-rubber material for primer. Very flexible.

C = Cohesion, A = Adhesion, CA = Combination of cohesion and adhesion.

TABLE II. (Continued)

System No.	Viscosity (20 RPM)	Thixotropic Index	Specific Gravity	Peak Exotherm and Minutes to Read	Flex (psi)	Tensile (psi)	Modulus of Elasticity	Type Failure	Comments
E_1	34,000 cps	6.80	1.25	46°C 5 min.	292	389	2.60×10^4	C	
K	23,800 cps	6.30	1.16	199°C 13 min.	1152	2631	5.0×10^5	CA	Fast cure, flexible.
B_2				30 min.	4856	1148	4.1×10^4	C	A flexibilized epoxy is added to increase flexibility.
J		not thixotropic		12 min.	2413	655	9.61×10^5	A	This system is an emulsion and was not thixotropic.

C = Cohesion, A = Adhesion, CA = Combination of cohesion and adhesion.

Page A - Performance of Sealants on Clean Tiles. If a material was believed to perform well on clean tiles (based on a judgment of chemical class or from manufacturer's data) then the clean tile test was dismissed and the material was subjected to the more strenuous sewage-soaked tile test.

Part B - Performance of Sealants on Sewage-Soaked Tiles.

Part C - Affects of Coupling Agents. The affects of coupling agents on the adhesion and physical properties of various chemical classes were observed. In many cases this modification was necessary before useful testing could be accomplished.

Part D - Affects of Curing Agents and Reactive Diluents. Some of the basic epoxy systems were tested with various curing agents.

Part E - Epoxy Polysulfide System. Data pertaining to use of polysulfide modifiers and various curing agents was recorded.

C. ADJUSTMENT OF SEALANT FORMULATIONS

Materials showing good tensile and flexural strength, good chemical resistance and good cure time were examined for proper application properties. Feedback from large-scale testing showed a material was needed with the ability to stay positioned within the pipe until cured but also be easy to pump. The property of thixotropy proved to be the solution.

Since acceptable application properties are indispensable, the problems of viscosity and thixotropy must be solved. The epoxy and urethane systems can be thixotroped by the addition of superfine, fumed silica. This filler has a true thixotropic effect--i.e., high apparent viscosity at low shear rates (slow stirring) and low viscosity at high shear rates (fast stirring). Note: The sealant that applied best during large-scale testing was made from a lower viscosity material (500 to 1,000 centipoise) and thixotroped to a high apparent viscosity material with a high thixotropic index. Samples of typical viscosities and thixotropies are given in Figure 6. Because the viscosity is low at high shear rates, the sealant is easily applied or mixed. The high viscosity at low shear rates gives the sealant sufficient body to stay fixed, without sagging, until cured.

Since the material thixotroped by the addition of fumed silica or other thixotropic modifiers can never have a viscosity lower than its original viscosity, diluents are useful in reducing the original viscosity to a suitable application range. The original viscosity of the sealant is approached at high shear rates after the sealant has been thixotroped. Any advantage of combining with the system rather than behaving as a plasticizer. Simce the properties desired can be achieved by the use of reactive diluents, there is no need for using nonreactive diluents.

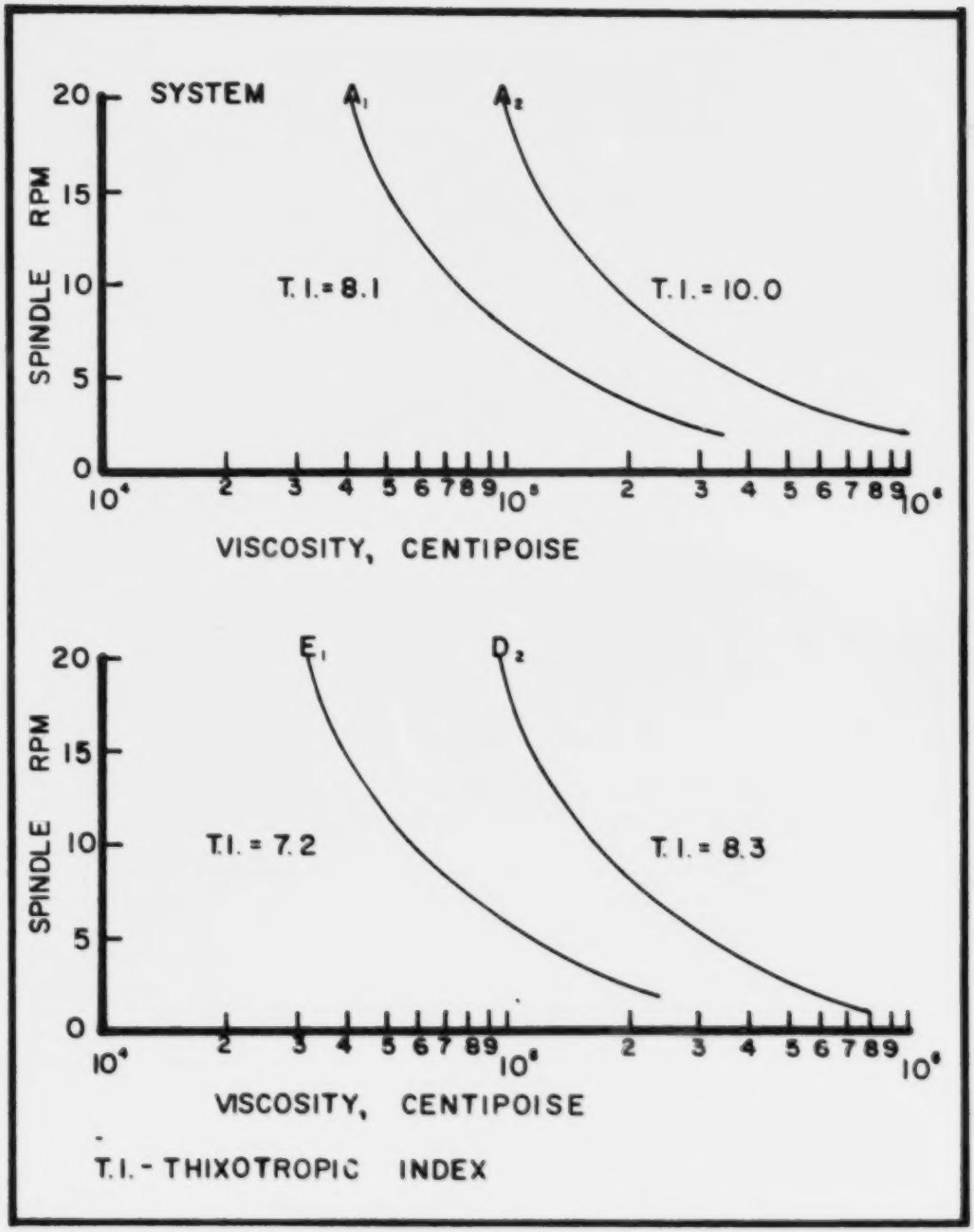

Figure 6. Viscosity Curves.

Appendix III part D contains useful information on the application of diluent and curing agents. Table III illustrates the affects on viscosity of adding various diluents and solvents.

Epoxy and urethane systems have the advantage of lending themselves to easy physical property modifications. Typically, the epoxy systems tend to be more rigid while the urethane systems tend to be more elastic. The epoxy system shown in Figure 7 has a wide range of variation between tensile strength and percent elongation. By varying the blends between diglycidyl ether of bisphenol A (DGEBA) and a diglycidyl ether of propylene glycol (DGEPG), the flexibility can be modified. The aromatic ring structure, as in DGEBA, usually gives hard, rigid cures with a low percentage elongation and low impact strength due to brittleness (Reference 11). By incorporating varying amounts of the polyglycol diepoxide, these properties can be changed. Better resistance to thermal shock is also obtained. Of course, the curing agent also affects these properties, but the important consideration in selecting a curing agent is the cure rate.

Generally, the epoxies showed better adhesion than the urethanes after soaking in water; however, the adhesion of both systems was improved by priming the substrate with -- or the addition of -- adhesion-promoting materials submitted by the manufacturers. Adhesion of the epoxies was benefitted either by priming with -- or by adding -- such silanes as gamma-aminopropylmethoxysilane or gamma-glycidoxypropyltrimethoxysilane. In most cases the addition of an adhesion promoting material was not required (see Tables IV through VIII and Appendix III, part B). In the case of the urethanes, the substrate must be primer. In the case of the epoxies, the silanes served as primers (see Appendix III, part B) and are also recommended as additives.

Proprietary names are listed only where description of the composition of a system would not be adequate otherwise. Although many products are interchangeable, usually the type of materials delt with here are not. If no proprietary names are given, then it may be assumed that any reputable material will perform adequately.

Materials for further testing and improvement were selected with the following parameters used as criteria with the order of importance (first to last) indicated:

1. Viscosity and thixotropy
2. Set or cure time
3. Chemical resistance
4. Tensile and flexural strength
5. Adhesion
6. Cost

Table I summarizes these systems. Table II given the physical properties of one of each class (A_1 and A_2 are one class, etc.)

TABLE III. Effects of Diluents and Solvents on DGEBA (Unmodified Viscosity = 16,000 Centipoise)

Diluent	Amount Diluent phr	Final Viscosity (cps)
Dibutyl phthalate	30	1,230
Dipropylene glycol	35	1,160
Dimethyl phthalate	35	1,155
Decyl glycidyl ether	16	1,110
Diethylene glycol	30	1,110
Allyl glycidyl ether	10	1,110
Cyclohexanone	17	1,040
Phenyl glycidyl ether	20	1,040
Styrene	11.5	1,005
Methylethyl ketone	7	960
Gamma-butyrolactone	15	960
Xylene	11.5	960
Diacetone alcohol	20	920
Cellosolve	12	860
X air (alkylether)	23	860
Butylglycidyl ether	12	860

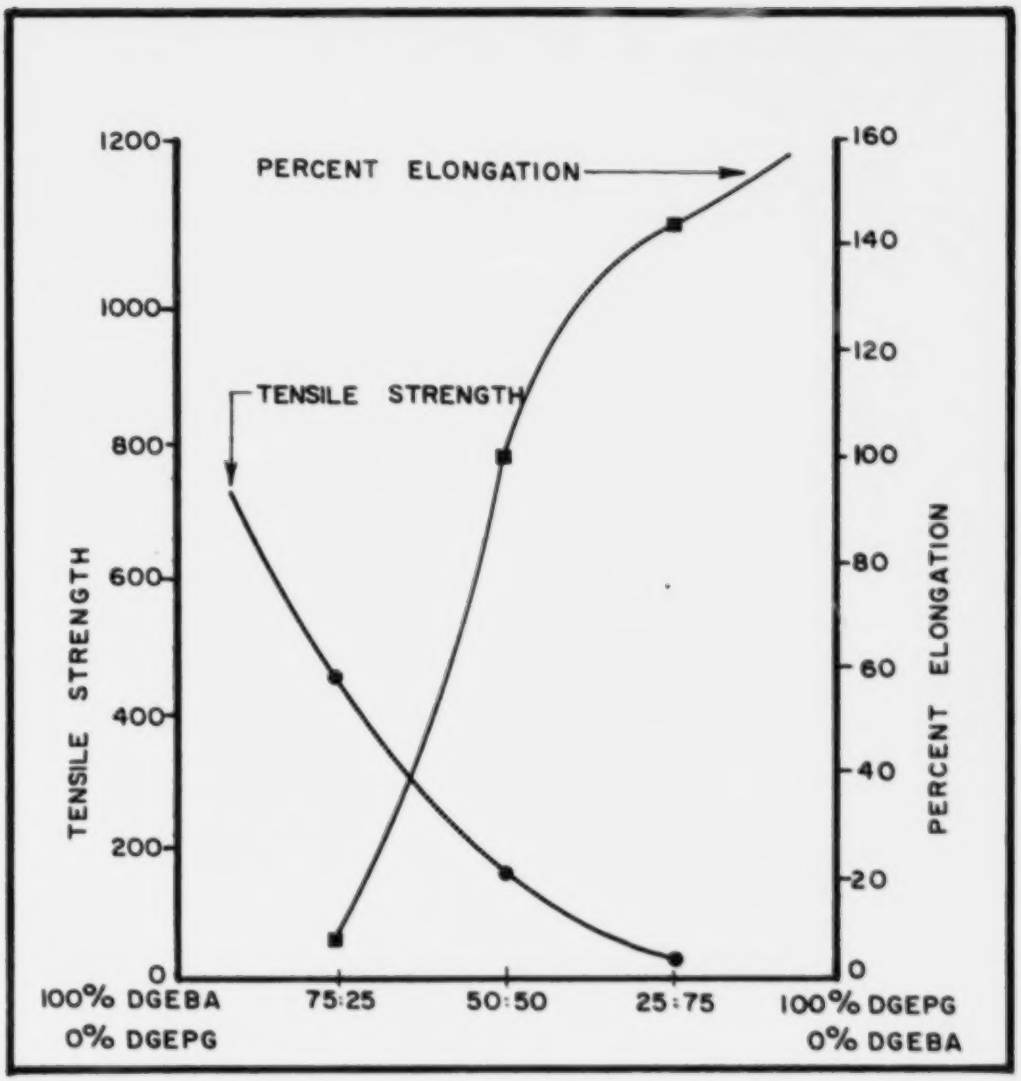

Figure 7. Tensile Strength and Elongation of DGEBA-DGEPG Blends cured With Araldite 963.

D. LARGE-SCALE TESTING

Sealants that passed laboratory tests (listed in Table II) were subjected to actual sealing procedures. A series of tests was devised to simulate conditions of repairs of failures on six-inch I.D. clay pipe.

1. Typical Failures Tested

The first failure (open joint) simulated the condition encountered if the spigot end of a pipe barrel were inserted into the bell with no jointing material or gasket. The distance between the two sections of pipe was adjusted to 1/8 inch to simulate separating sections. Similar conditions were found where sewer-pipe cleaning operations or ground movements had separated pipe section. Figure 8 shows a joint repair with excess pipe broken away to show smooth interior.

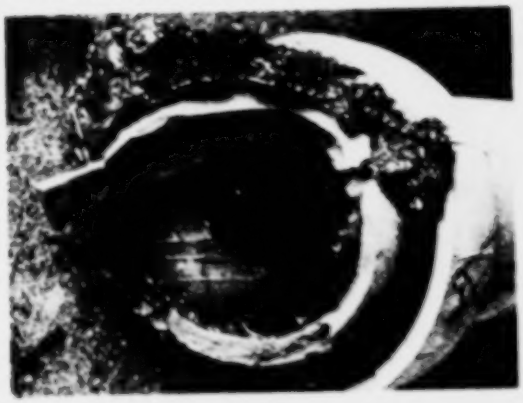

Figure 8. Joint Repair

Figure 9. Broken Bell

The second failure (broken bell) was set up in the same way as the open joint except that approximately one third of the bell section was broken away (Figure 9).

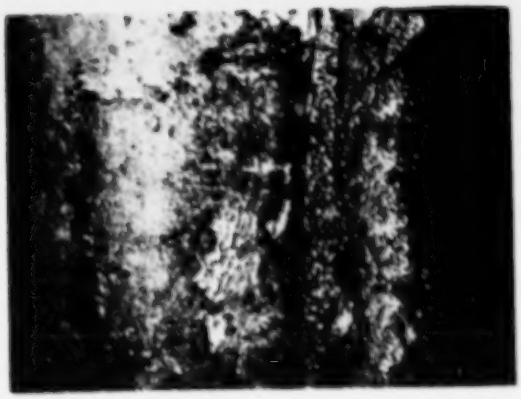

Figure 10. Barrel Crack

Figure 11. Hole in Barrel

The third failure was a simulated crack in the barrel of a pipe. A slot was sawed through the barrel approximately 1/8 inch wide by 3 inches long. Figure 10 shows a repaired crack with excess sealant and loose dirt removed to show edge bonding.

Any sealant successfully patching the first three failures was used to patch a fourth and more strenuous failure. This test was considered to be a supplement to the other tests rather than a criterion for passing or failing a candidate sealant. A square hole, 3-1/2 inches on each side, was cut through the barrel to be repaired (Figure 11). Here again the excess sealant and loose dirt was removed to show the edge bonding.

2. Methods of Testing

The failures to be sealed were placed in a box (Figure 12). This box was constructed so that the pipe sections were supported and restrained by saddles in the box to prevent movement as the sealant was applied. The six-inch test pipe was soaked in water, then placed in the box such that the failure was between the saddles. The pipe was covered on all sides with chernozemic soil, leaving the ends exposed. Chernozemic soils are high in clay content, and are plastic and subject to great shrinking and swelling (Reference 8). This soil was selected because it is a type involved in several of the major causes of infiltration listed in Section I. A mock packer (Figure 13) was placed in the pipe so that the failure was between the rubber seal rings, which were then expanded mechanically. The sealant was then pressurized from the injector into the packer, out into the area between the sealing rubber rings and into the flaw, or sewer pipe failure. After five minutes, the packer was deflated and removed from the pipe. If no obvious visual flaws were found in the repair, then the repaired section

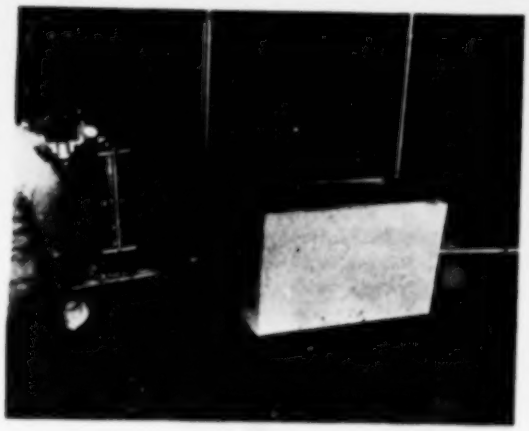

Figure 12. Test Box.

Figure 13. Mock Packer

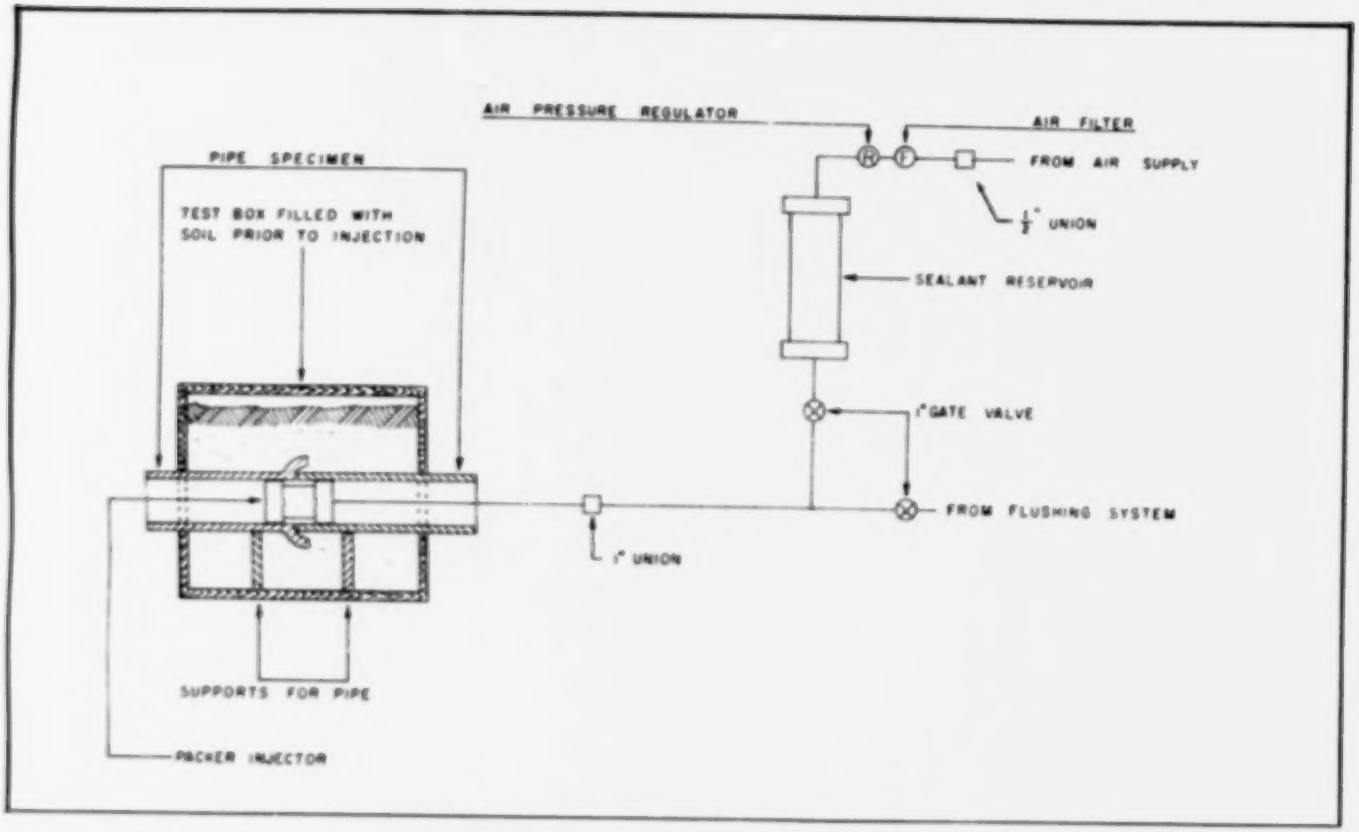

Figure 14. Large-Scale Testing Apparatus-Schematic

was tested. If a primer was required, it was applied before the sealant and in the same manner as the sealant. A 30-minute delay was then allowed before application of the sealant. Figure 14 is a schematic of the sealant application and the test box.

Repairs that appeared to be sealed were tested by placing the repaired section in a hot-cold pressure box (Figure 15). This box was constructed so that a pressure of 13 psi, equivalent to a 30-foot head of water, could be applied to the exterior of the pipe. Infiltration or leakage could then be determined by a drop in pressure or by visual observation inside the pipe. If, at this point, the seal was inadequate, the repair was repeated to check against faulty procedure. If the repair again leaked or showed signs of poor adhesion, the candidate was eliminated from the remainder of the test schedule.

If results of the leak test were good, the repaired section was tested for flexibility (this test applied only to joints). The flexibility test simulated the results of ground movements on the joint seal (Figure 16 shows the test rig). The test was accomplished by supporting the ends of the pipe sections and inducing slight repeated displacements at the joint. First, the pipe was pressurized internally to about 5 psi to indicate if or when the seal began to leak. The joint was deflected 0.1-inch downward then 0.1-inch upward from center. The results were reported as acceptable if no leak occurred. If a small leak occurred, the amount of leak was reported in milliliters per minute at 5 psi. If the bond ruptured during the test, the type of failure was determined (adhesive, cohesive, or adherent). This flexure test was designed specifically for this program and is not to be confused with ASTM Standard Specification C-425 which covers resilient joints installed on the pipe at the factory.

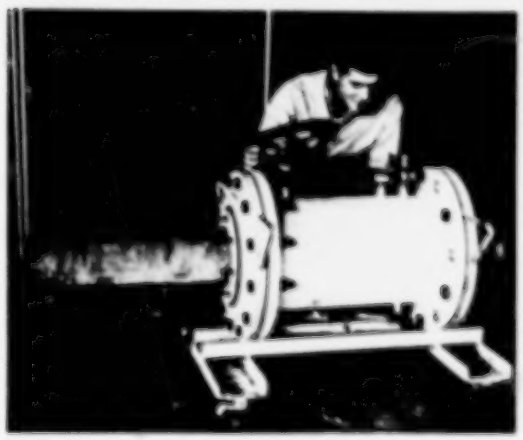

Figure 15. Hot-Cold Pressure Box.

Figure 16. Flexibility Test Rig.

After a selected sealant had undergone the above tests, the repaired pipe was again placed in the leak test box (Figure 15) and subjected to a series of hot and cold cycles under non-pressurized conditions. Both the pipe and the box were filled with water (heated to 90°F) and allowed to remain for 10 minutes. After this time, the box was drained, leaving only the

pipe filled with 90°F water. After 10 minutes in this condition, the pipe was drained and both the pipe and box were refilled with 34°F water, and this temperature maintained for 10 minutes. Then the box was drained, leaving only the pipe filled with 34°F water, to be drained 10 minutes later. This completed the end of a cycle. Each repair was tested for 25 to 100 cycles, and visually inspected before beginning the high-pressure test.

The repaired pipe was again placed in the leak test box and pressurized slowly to 5.0 psi and held for 10 minutes. The pressure at which rupture occurred was reported. Or, if no rupture occurred, the repaired pipe was pressurized internally to 13 psi and held for 10 minutes. The test rig was then dissassembled and the repaired section was visually examined for changes and stored for future reference.

3. Results of Large-Scale Testing

By using the conditions and methods described above for large-scale testing, a series of tables were prepared that contained data from tests performed on systems described in Table II.

Table IV.	Repair of Clean 6-Inch Sewer Pipe Joint.
Table V.	Repair of Crack in Barrel.
Table VI.	Repair of Missing Bell Section.
Table VII.	Repair of Hole in Barrel.
Table VIII.	Repair of Sewer Pipe Soaked in Sewage.

From these data the following acceptable systems were derived.

System A_1: A basic epoxy system (DGEBA) diluted with a reactive diluent. This system is very strong and has almost no flexibility, resulting in a broken pipe if the sealed joint is strained. System A_2 is a higher viscosity version of A_1.

System B_1: A basic epoxy blend of DGEBA and DGEPG. The viscosity and thixotropy of this system are nearly identical to System A_1 leading to nearly identical application properties. System B_1 differs from System A_1 in flexibility and tensile strength and is more suitable in applications where pipe movement is possible but with a compromise in tensile strength.

System C_2 is still a more flexible epoxy system of the same material obtained by increasing the DGEBG/DGEBA ratio (Figure 7).

System D_1: Dickey's D-CUE 1072-31 (a polymer urethane) thixotroped by the addition of Cabosil M-5 or Aerosil and Tween 80 (Polyoxyethylene (20) sorbitan mono-oleate). System D_2 is a more viscous, more thixotropic version of D_1. A primer is necessary for maximum adhesion.

System E_1: Dickey's B-430 (polyether urethane) thixotroped by the addition of Cabosil M-5 or Aerosil and Tween 80. System E_1 differs from

TABLE IV. Repair of Clean 6-Inch Sewer Pipe Joint.

Candidate System	Leak Test	Leak Test with Pressure	25 Hot & Cold Cycles	Final Pressure Test	Comments
G_1	F		-	-	Thixotropic index was too low, material flowed to the bottom of the joint.
G_2	P	Failed at .060 inch downward deflection	-	-	Fumed silica increased thixotropic properties. Epoxy system needed more flexibility. (100% solids epoxy paint.)
F_1	F		-	-	Test rig blew an air hole in the epoxy and caused a water leak. Hard to pump, very sticky.
F_2	P	Failed at .040 inch downward deflection	-	-	Used fumed silica instead of asbestos because the silica system was easier to pump. (Epoxy-polyamide system.)
H	P	Failed at .025 inch downward deflection	-	-	Material was found not to cure completely in soil and did not adhere to pipe. (Polyester, room-cured.)
I	P	Failed at .100 inch upward deflection	-	-	Good flexibility, but slow to cure (48 hours), bonding was poor. (Epoxy based concrete sealer and primer.)
D_1	P	P	P	P	Practical use of primer. Must have primer used before it will adhere to pipe. Phenolic nitro-rubber compound needed as primer. (Urethane)

P = Passed. F = Failed.

TABLE IV. (Continued)

Candidate System	Leak Test	Leak Test with Pressure	25 Hot & Cold Cycles	Final Pressure Test	Comments
E_1	P	P	P	P	Low-viscosity version of D_1, also needed primer as D_1.
J	F		-	-	Too thin, unable to thixotrope (an emulsion).
A	P	Failed .007 inch downward deflection	P	P	Epoxy failed, broke sewer pipe. For this reason, a second test was made to subject system to hot and cold cycling. Used epoxy-terminated silane to improve adhesion.

P = Passed. F = Failed.

TABLE V. Repair of Crack in Barrel.

Candidate System	Pressure Test	Comments
E_1	Internal pressure of 13 psi at 10 minutes. No leakage. External pressure of 30 psi, crack began to leak.	Phenolic nitro rubber must be applied before E_1 to obtain water-tight seal.
A_1	Passed internal and external pressure tests.	Used epoxy silane to improve adhesion.
D_1	Passed internal and external pressure tests.	Phenolic nitro rubber must be applied before D_1 to obtain water-tight seal.

TABLE VI. Repair of Missing Bell Section.

Candidate System	Leak Test	Pressure Test	Comments
E_1	Passed	Passed internal test of 10 psi for 10 minutes with no leaks. Passed external test of 50 psi.	Phenolic nitro rubber primer required.
D_1	Passed	Internal test of 10 psi for 10 minutes, no leakage. External test of 50 psi for 10 minutes, small leak.	Phenolic nitro rubber primer required.
A	Passed	Leaked at 3 psi.	Silane coupler used. Reason for leakage was air bubble in bottom of joint.

TABLE VII. Repair of Hole in Barrel.

Candidate System	Leak Test	Pressure Test	Comments
E_2	Passed	Held at 50 psi for 7 minutes before leakage was observed.	Phenolic nitro rubber primer was required.
D_2	Passed	At 15 psi there was a leak of one drop per second, at 50 psi this rate remained unchanged.	Phenolic nitro rubber primer was required. Very thick and hard to pump.
A_2	Failed		Unable to make Epoxy system thixotropic enough to bridge hole in pipe barrel.

TABLE VIII. Repair of Sewer Pipe Soaked in Sewage.

Candidate System	Leak Test	Flex Test with Pressure	25 Hot & Cold Cycles	Final Pressure Test	Comments
A_1	P		P	Small leak at 30 psi. Did not increase when raised to 50 psi.	Did not run flex test because epoxy and pipe had same approximate strength.
D_1	P	Leaked when flexed downward .1 inch, stopped when returned to 0 and flexed upward .1 inch.	P	Some leakage at 50 psi.	Phenolic nitro-rubber primer required.
E_1	P		P	Failed. Leaked at 13 psi.	Phenolic nitro-rubber primer required.

P = Passed.

System D_1 mainly in viscosity. System E_2 was created by increasing the concentration of Tween 80 in System E_1). A primer is necessary for maximum adhesion. #

System K: An epoxy-based system similar to System B except that the hardener was changed to Araldile 963 (modified polyamide), yielding a much more flexible system and also a faster curing system.

All the systems mentioned above performed adequately as sewer pipe sealants.

Adapting the above systems to actual field conditions is a problem which only field test experience can solve. All systems mentioned above are believed to perform adequately as sewer pipe sealants but it is possible that one system could be better than another under specified conditions.

System A_1 and A_2 (epoxies) are strongest (tensile and flexural strengths) but have low flexibility. Strain of a repair made with these systems would problaby result in a broken pipe before failure of the repair.

Systems B_1, C_2 and K (epoxies) are more flexible systems but with a sacrifice in tensile strength. If soil shift occurred, these systems would allow pipe movement without rupture to a point and then failure at the repair would occur.

Systems D_1, D_2, E_1 and E_2 (urethanes) are more elastic than the epoxy systems and allow more freedom of pipe movement but are complicated by the rise of primers before good adhesion to the sewer pipes can be obtained. As for the type of repair to be mended (crack, hole, joint, etc.) all systems compare similarly and favorably.

A number of properties of the grouting materials were selected which were anticipated to be important in their evaluation. These properties are shown in Table IX. An arbitrary value of 100 was assigned to each ideal property. Prior to the initiation of the program an estimate was made of the probable approach to the ideal by making formula modifications. The table compares the properties of the best six materials to the ideal and probable achievable properties. This estimate is shown in Appendix IV.

Prior to initiation of the program, it was believed that an ideal viscosity would be that of water. However it was found that a dynamic (pumping) and a static (placed) viscosity were important properties. The ideal for dynamic conditions is the viscosity of water while the static viscosity ideal would be that of a non-sagging or non-dripping putty. Certain materials have the property of shear thinning under dynamic conditions and thickening under a static condition. This property is commonly called thixotrophy. As explained previously additives were included in the sealant formulation to improve the thixotropic property.

W. S. Dickey recommends phenolic nitro rubber primer and suggests only good housekeeping procedures in regard to possible toxicity.

TABLE IX. Sealant Properties Compared With Ideal

Material	Properties										Remarks
	Cost of ($ /lb.) of Sealant	Viscosity		Adhesion	Strength	Flexibility	Concentration	Pot Life	Shrinkage		
		Dynamic	Sealant						Cure	Environment	
IDEAL MATERIAL		100	100	100	100	100	100	100	100	100	The ideal material will have a dynamic viscosity of water and static viscosity of putty, adhesions equivalent to breakage, strength equal to sewer pipe, flexible as the sewer pipe, contamination to not materially affect strength, a pot life which is adjustable and no leaks resulting from shrinkage.
PROBABLE ACHIEVABLE		85	85	100	100	100	85	90	100	100	Estimate of probable achievable approach to the ideal properties prior to program initiation.
System											
A_1	.75	25	70	90	100	100	85	90	100+	85	The viscosity of the sealants while being pumped is less than ideal. The other properties of the sealants are rated good to excellent. The environmental shrinkage was excellent but because of the lack of data over a period of time longer than a year the ratings were estimated to be 75 to 85.
A_2	.75	15	75	90	100	100	85	90	100+	85	
B_1	.75	25	72	85	100	100	85	90	100+	70	
C_2	.75	25	70	80	100	100	85	90	100+	70	
D_1	.97	12	80	70	90	100+	70	85	100+	80	
D_2	.97	9	85	70	90	100+	70	85	100+	80	
E_1	.97	15	75	70	90	100+	70	85	100+	80	
E_2	.97	10	80	70	90	100+	70	85	100+	80	
K	.75	25	70	80	100	100	85	90	100+	75	

E. SEALING EQUIPMENT INVESTIGATION

1. Existing Equipment

This section details the investigation and evaluation of existing equipment for applying sealants in the field and recommends improvements and developments for application of the new and improved sealants developed under this contract. Figure 17 is a schematic flow diagram of one system of sealing sewer leaks with the acrylamid gels. Figure 18 is another system flow diagram for acrylamid gels. It should be noted that the principal difference in these systems is in the movement and metering of the gel components. All of the sealing contractors investigated used one or the other of these systems.

Operation of the acrylamid gel sealing system is as follows. The acrylamid and catalyst are mixed with water in their respective mixing tanks. Each mixed solution is metered and moved through separate hoses to the packer-sealer. The two solutions are released into the pipe around the packer and forced into the leak. The joining of the chemicals allows them to react, making a gel within a few seconds.

There are a number of sealing packers being used today. All existing equipment is similar in sequence of operation and in function of the various parts. All have inflatable elements to isolate the leak, air lines for inflation, two pipes for delivering the chemical grout and catalyst to the packer, and necessary towing lugs. Some of the packers have protective end shoes which are larger in diameter than the inflatable units and afford some protection to the inflatable unit from abrasion. These packers have either two or three inflatable sections. The majority of the packers have an open center which allows the sewage to continue to flow during a sealing operation.

Figure 19 shows a typical packer having two inflatable sections. It is also typical in that the chemical grout and catalyst are not allowed to mix until outside of the packer. This technique requires the major mixing to take place in the annulus (between packer and pipe) which has been isolated by the inflation sections.

This method of mixing depends on the random collision of grout and catalyst molecules. It is evident that an ideal mixture could (except for a highly improbably random event) be expected to result only from a systematic mixing process.

Figure 20 shows a typical packer having three inflatable sections. The two inflatable end sections isolate the leak and, after injecting the grout, the center section is inflated to displace the grout from the annulus between the packer and the line. The chemical grout and the catalyst are discharged from the two supply pipes at a point under the center inflatable section. The mixing of sealant and catalyst is again a random event, occuring under the inflatable section or in the area between the packer and the pipe.

2. Recommended Equipment Changes

The chemical sealants developed under this contract are mixtures of component chemicals which, on polymerization, form rigid or flexible materials.

One packer-sealer design which could be used in applying the new sealants is shown in Figure 21. This packer will work similarly to the ones currently in use. It has air inflation tubes for leak isolation and an air inflation tube for forcing sealant from the annulus. A single pipe will provide a travel path for the sealant from the adjacent mixer. If desired, a non-stick coating such as tetrafluorethylene could be applied to all surfaces coming in contact with the sealant. The center is open so that sewage can continue to flow during a sealing operation.

The physical properties of these components and their reaction chemistry requires complete and thorough mixing before using the resulant blend in the sewer pipe. The mixing must be positive, with direct shearing action performing the best. Mixing power must be supplied from outside, not by movement of materials through the mixing chamber.

It has been noted that there is no positive mixing system on any application equipment currently being used; therefore, before any existing equipment is used for applying the new sealant materials, a system for adequately mixing the components will be required on each application machine. Figure 22 shows a screw-type mixer which has a positive mixing action and could be attached to a suitable packer supply pipe. Further, since these sealants polymerize to a firm adherent plastic, the packer-sealer having three inflatable sections could not be used because the sealant could collect under the center section set up, and render the packer unusable.

Figure 23 is a schematic flow diagram of the system to use the new sealants developed under this contract to seal leaking sewers. The similarity between this system and the acrylamid system that uses the metering pumps is readily apparent; however, for the acrylamid system, a one-to-one ratio between catalyst and grout is used, while the new sealants require a ratio of part A (sealant) to part B (hardner) of about five-to-one. Therefore, a pump modification will be necessary. In the event a primer is to be used, an additional line would need to be added to the packer-sealer (Figure 21). The primers are one component systems of water thin viscosity and require no additional mixing.

The other acrylamid system uses air to transport the chemicals and meters them through rotameters. The new sealants are too viscous to be moved by air over long distances or to be metered through any area type meter; therefore, some modification will be necessary before this system can be made usable with the new sealants: e.g., the air delivery system must be changed to positive-displacement pumps, and the rotameter eliminated.

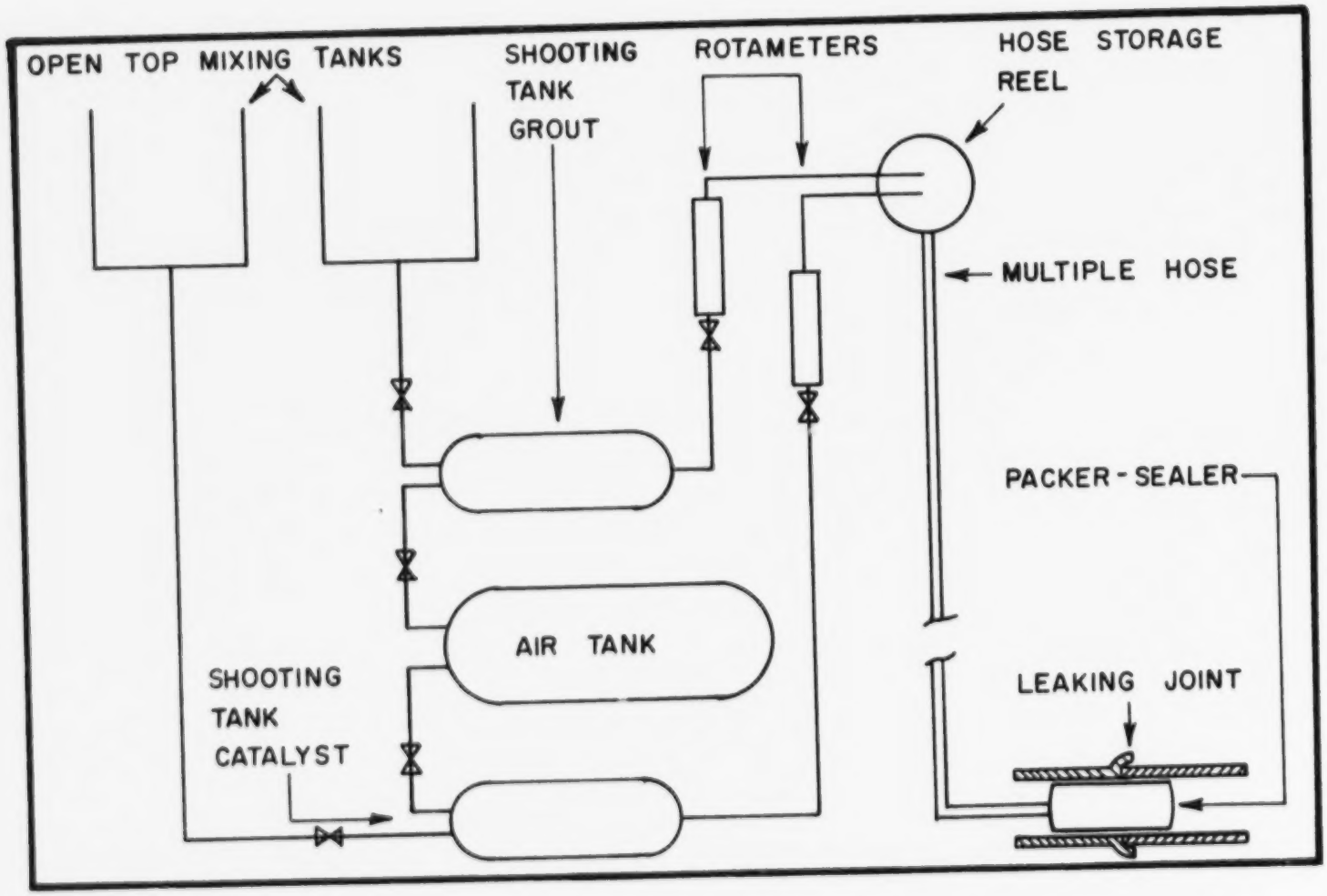

Figure 17. Acrylamid Sealant System-Schematic.

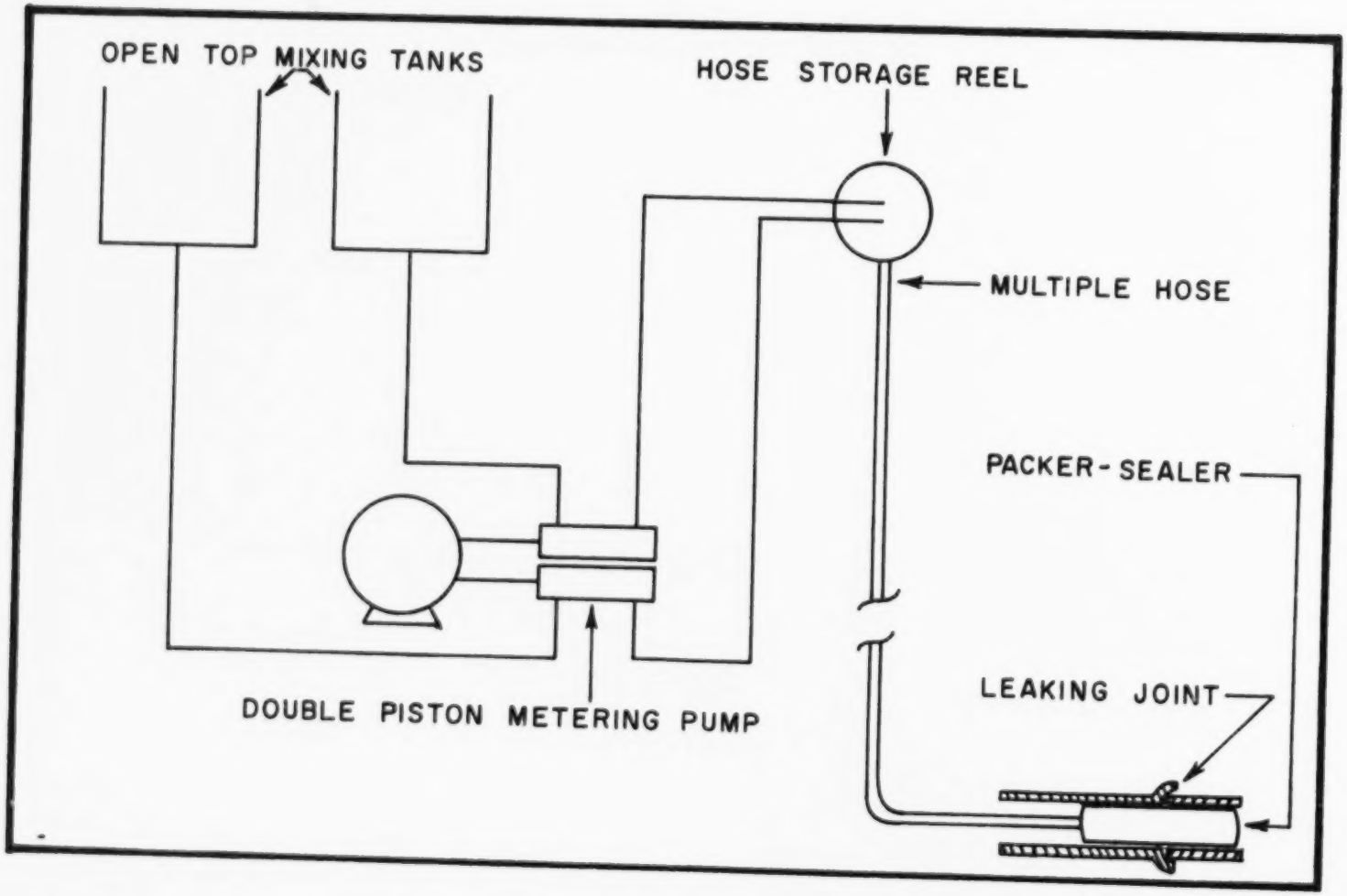

Figure 18. Acrylamid Sealant System-Schematic.

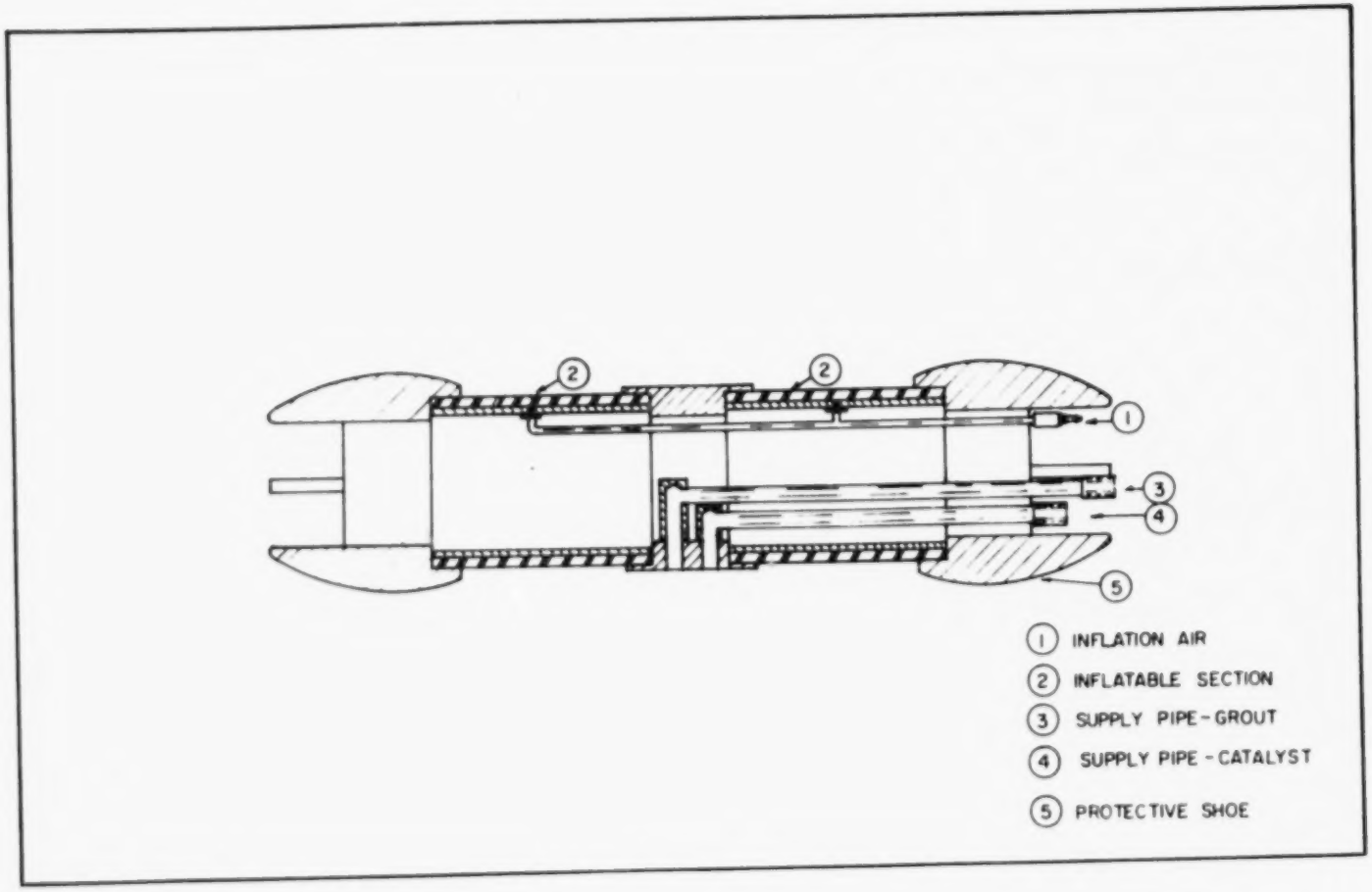

Figure 19. Packer-Sealer With Two Inflatable Sections.

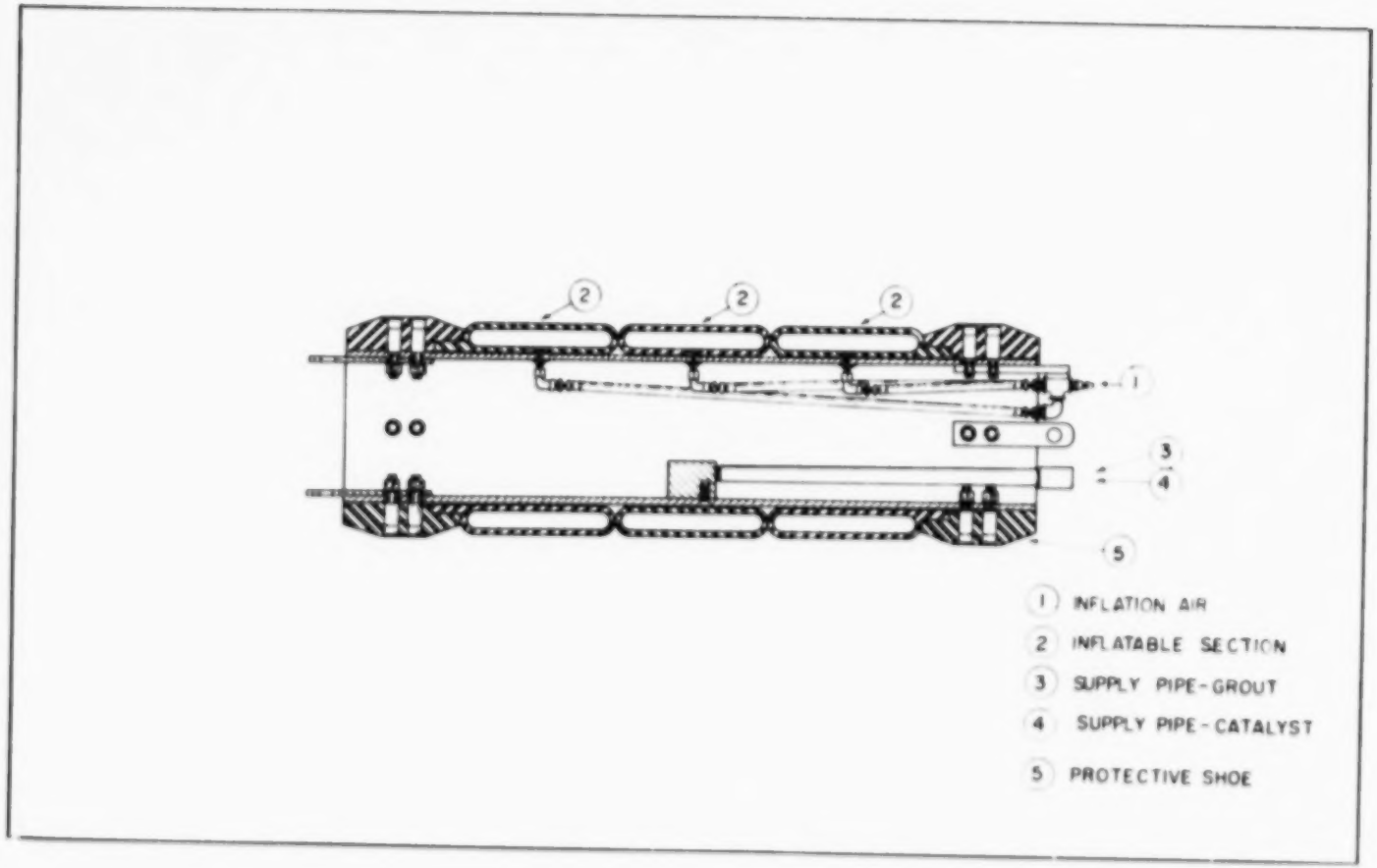

Figure 20. Packer-Sealer With Three Inflatable Sections.

grout, the center section is inflated to displace the grout from the annulus between the packer and the line. The chemical grout and the catalyst are discharged from the two supply pipes at a point under the center inflatable section. The mixing of sealant and catalyst is again a random event, occuring under the inflatable section or in the area between the packer and the pipe.

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The physical properties of these components and their reaction chemistry requires complete and thorough mixing before using the resultant blend in the sewer pipe. The mixing must be positive, with direct shearing action performing the best. Mixing power must be supplied from outside, not by movement of materials through the mixing chamber.

It has been noted that there is no positive mixing system on any application equipment currently being used; therefore, before any existing equipment is used for applying the new sealant materials, a system for adequately mixing the components will be required on each application machine. Figure 20 shows a screw-type mixer which has a positive mixing action and could be attached to a suitable packer supply pipe. Further, since these sealants polymerize to a firm adherent plastic, the packer-sealer having three inflatable sections could not be used because the sealant could collect under the center section set up, and render the packer unusable.

Figure 21 is a schematic flow diagram of the system to use the new sealants developed under this contract to seal leaking sewers. The similarity between this system and the acrylamid system that uses the metering pumps is readily apparent; however, for the acrylamid system, a one-to-one ratio between catalyst and grout is used, while the new sealants require a ratio of part A (sealant) to part B (herdner) of about five-to-one. Therefore, a pump modification will be necessary.

The other acrylamid system uses air to transport the chemicals and meters them through rotameters. The new sealants are too viscous to be moved by air over long distances or to be metered through any area type meter; therefore, some modification will be necessary before this system can be made usable with the new sealants: e. g., the air delivery system must be changed to positive-displacement pumps, and the rotameter eliminated.

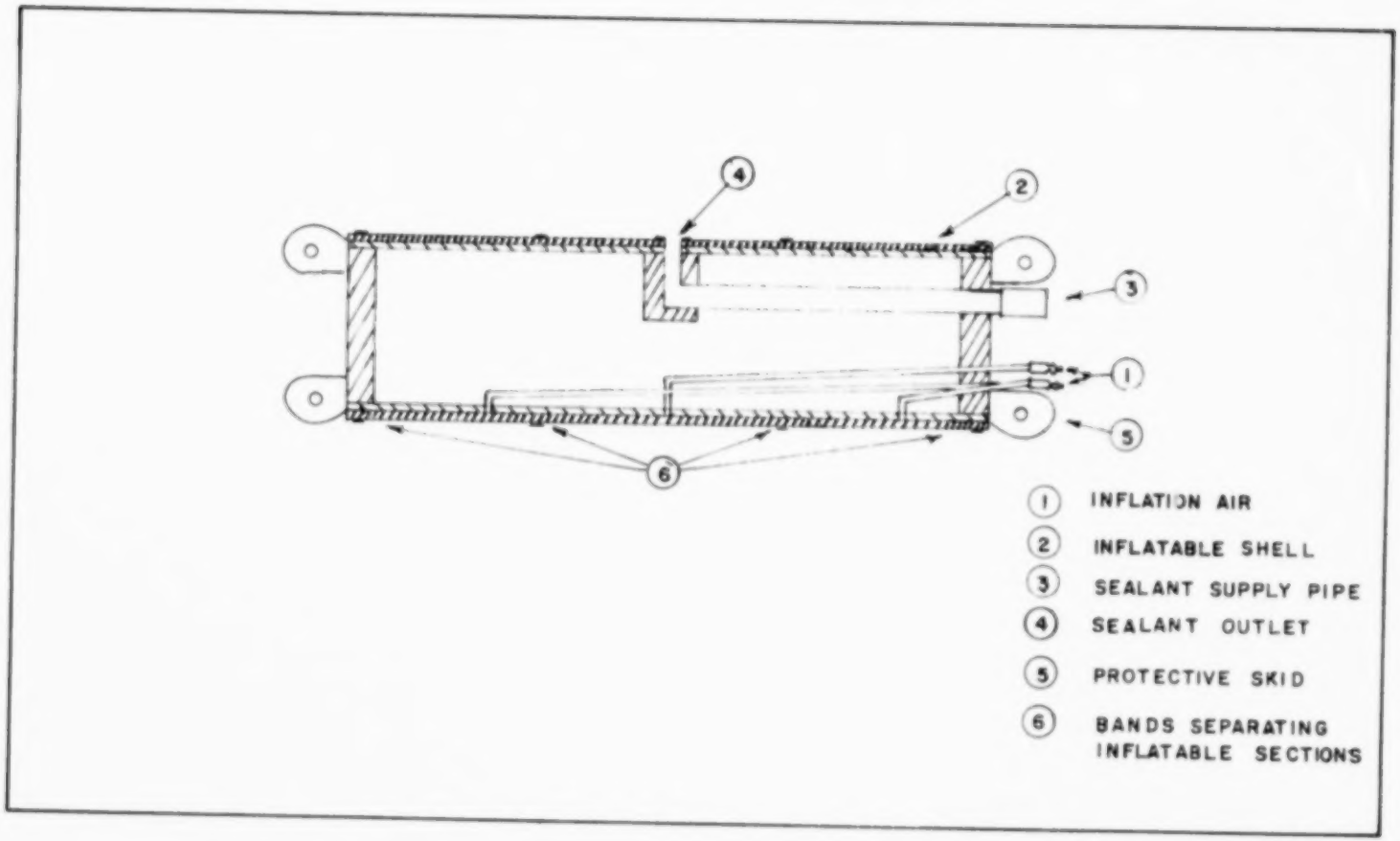

Figure 21. Packer-Sealer for New Sealant.

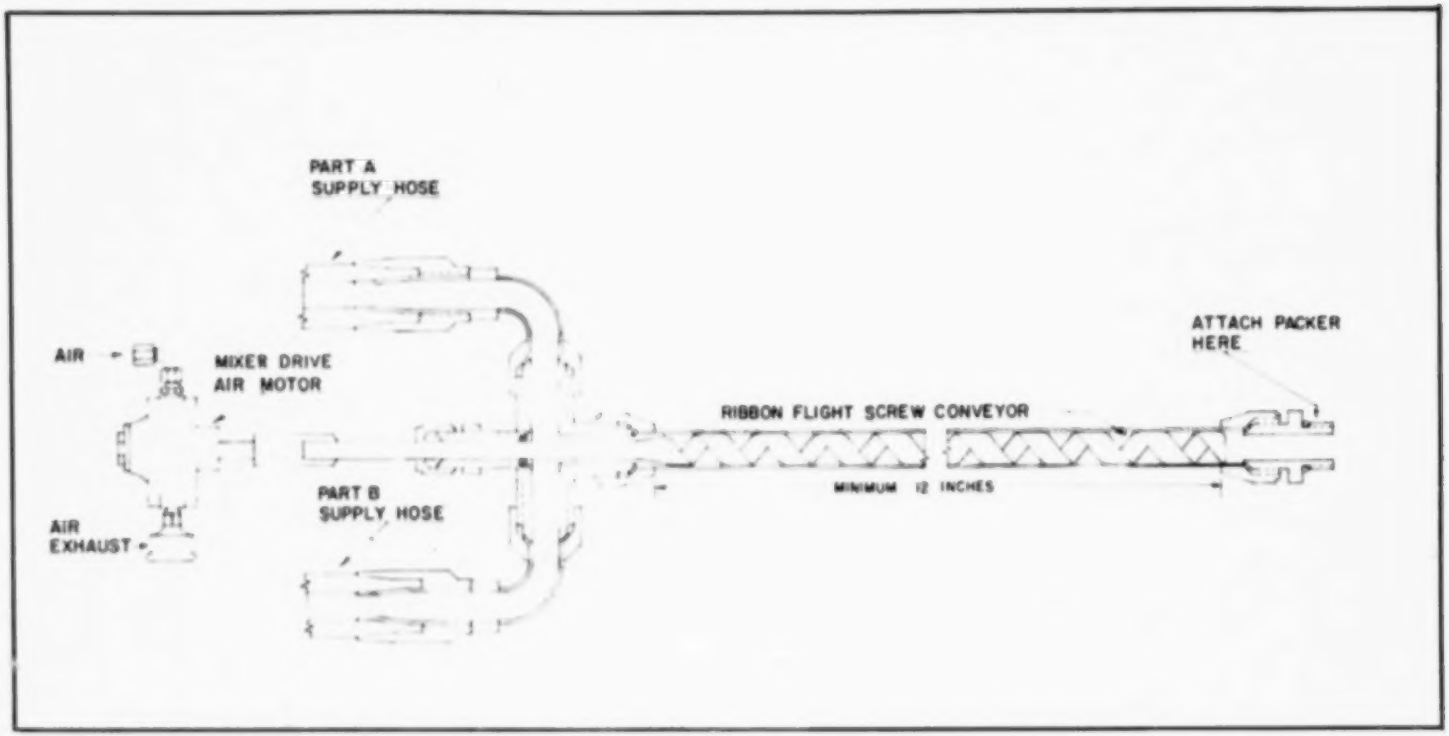

Figure 22. In-Line Mixer for New Sealants.

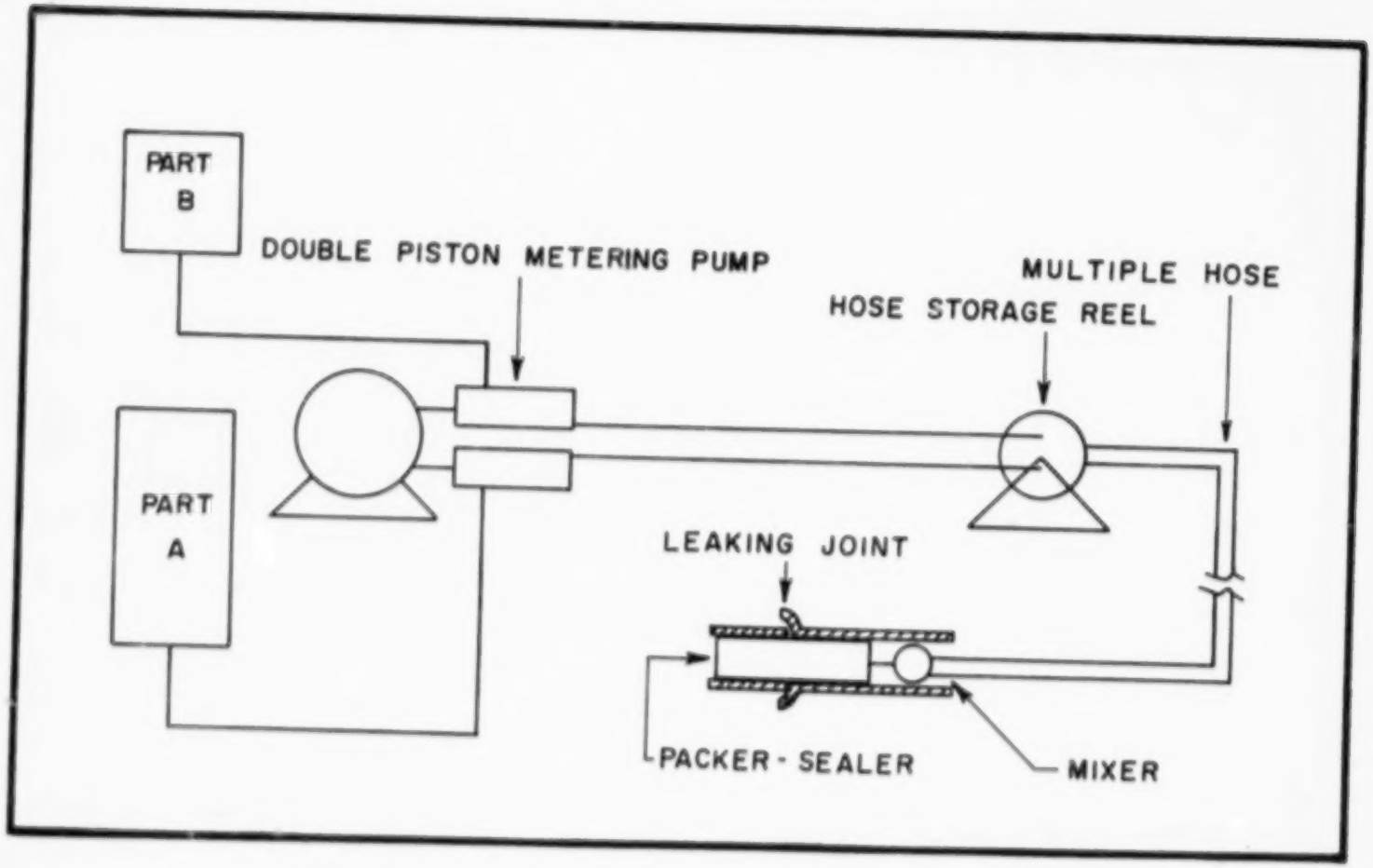

Figure 23. Improved Sealant System-Schematic.

While some of the existing sealing equipment could be used with some modifications, it is believed that these new sealing materials could best be applied with a completely redesigned packer and surface equipment.

F. COST EFFECTIVENESS STUDY

1. Basis of Cost

A typical internal sewer sealing operation is begun by clearing the line of large or bulky debris. To do this, a "porcupine," or a ball or other device is pulled through each section. The crew then pulls the television camera through each section while an engineer monitors the television screen. All breaks, leaks, line and grade deviations, and other pertinent information are recorded along with the footage from the manhole to the trouble encountered. Analysis of the field data pinpoints each leak, enabling the sealing crew to easily locate the leaks discovered during the television inspection. The leak-locating operation is kept separate from the sealing operation because sealing is much slower. This segregation allows a better utilization of personnel and equipment.

In the sealing process, a packer is pulled through the line to the leak. The packer is positioned at the fault and inflated, thus isolating the leakage from the rest of the pipe. Separate hoses to the packer carry the acrylamid grout and the catalyst, both in liquid form, to the packer under pressure. In the packer the two chemicals are mixed by jet action. The resulting mixture passes into the leak and out into the surrounding soil. As it solidifies into a gel it seals in the fault and around the outside of the opening. The packer is then deflated and a television re-inspection is made of the repair.

With the new sealants, cleaning and leak locating are still necessary. The sealing process is one of pulling the packer to the faulty joint and inflating the end tubes to isolate the leak from the rest of the pipe. Separate hoses carry the part A (sealant) and part B (hardener) to the mixing chamber and then to the packer under pressure. The resulting mixture is forced from the pipe into the leak. The center tube is inflated and the sealant is further forced out of the pipe. All tubes are then partially deflated and the packer moved up and down the pipe to remove excess sealant. The packer is then deflated and the television camera is positioned for re-inspection of the repair.

If the period of time between leak-sealing operations is longer than the cure time of the mixed sealant, it will be necessary to flush the mixing chamber and packer with a suitable solvent. At the end of each day's operation, a thorough cleaning of the mixing chamber and internal portions of the packer with a suitable solvent will be necessary. Thus, the labor cost of sealing leaks in a sewer line breaks down into four basic operations: 1) cleaning the line for most efficient video observation, 2) television examination of the interior of the sewer pipe, 3) sealing the leak, and 4) video re-inspection of the results. The equipment cost for sealing leaks in a sewer line will consist of depreciation, operating costs and maintenance

costs. Since the underground and surface equipment are similar in both existing sealant systems and the new sealant system, no significant difference in acquisition cost is anticipated. The depreciation should then be about the same magnitude for both new and old systems. The operating and maintenance costs are expected to remain in the same range with both new and old systems since the unit operations and equipment are essentially the same.

The materials cost for sealing sewer pipe will include the cost of chemicals, catalysts, accelerators retarders, flushing solvents, primers and solvents for equipment clean-up.

2. Costs of Existing Sealing System Operation.

The published reports of four sewer sealing jobs and one letter report of a sealing operation were examined and costs extracted from the reports. Table X summarizes the pertinent data for each repair.

TABLE X. Cost of Inspection And Repair By Using Acrylamid Gel.

Item	Feet Pipe Inspected and Repaired	Total Cost	Number of Repairs	Cost Per Repair
1	2,070[1]	$ 5,015.00	28	$179.00
2	5,630[1]	7,095.00	63	112.00
3	12,442[1]	15,440.00	104	148.00
4	52,800[2]	151,530.00	1,056	143.00
5	10,550[3]	17,000.00	198	86.00

1. Reference 6
2. Reference 7
3. Correspondence from City of Billings, Montana, to The Western Company.

The average cost from Table X is $133.60 per repair. This cost includes 1) labor for cleaning, leak finding and leak repair, 2) equipment costs and 3) cost of chemicals. Since the labor and equipment costs are estimated to be the same with both the existing acrylamid gel system and with the new sealant, only the cost of chemicals will be compared.

The acrylamid gel solutions, when prepared as a water solution which contains 10 percent solids on polymerization, costs $2.00 per gallon of gelled material.

An acrylamid usage of three gallons per joint repair was reported by a leader in the business of inspecting and sealing sewer lines. This amount, confirmed by operating personnel of another company, is the average used for all size pipes from 6 inches to 24 inches in diameter. (A closer breakdown, by pipe size for example, was not released by either company). This usage results in a chemical cost of $6.00 per repair, including all chemicals, catalysts, accelerators and retarders. Flushing solvents, primers and solvents for clean-up of equipment, are not necessary with the acrylamid gels.

Epoxy sealant system usage, projected by pipe size, for joint repair is in pounds per repair:

6-inch	2.8 lb	15-inch	7.4 lb
8-inch	3.9 lb	18-inch	8.8 lb
10-inch	4.9 lb	21-inch	10.2 lb
12-inch	5.8 lb	24-inch	11.7 lb

Current basic chemical costs for the epoxy sealant and hardener are $.75 to $1.05 per pound, with the lower price based on volume orders. It is estimated that flushing and clean-up solvent will amount to a maximum of 0.25 gallon per repair, based on 20 repairs made per day. Almost any petroleum-base solvent will suffice for the reacted expoxies; e.g., naptha, stoddard solvent, cellosolve and others. Naptha, at $.80 per gallon, is a mid-range cost solvent. By using these cost figures, the epoxy system chemical cost per repair, by pipe size is:

6-inch	$3.12	15-inch	$ 7.95
8-inch	4.30	18-inch	9.45
10-inch	5.35	21-inch	11.10
12-inch	6.30	24-inch	12.50

The urethane system use projected by pipe size for jointing repair is:

6-inch	3.1 lb	15-inch	8.1 lb
8-inch	4.3 lb	18-inch	9.6 lb
10-inch	5.3 lb	21-inch	11.4 lb
12-inch	6.4 lb	24-inch	12.9 lb

Current basic chemical costs for urethane sealant and hardener are $.97 to $1.65 per pound, with the lower price based on volume orders. It is estimated that flushing and clean-up solvent will amount to a maximum of $.20 per gallon per repair based on 20 repairs per day. Most ketones and aromatic hydrocarbons are suitable for flushing and clean-up of unreacted urethanes. Methyl ethyl ketone, at $1.00 per gallon, is a mid-range cost solvent. By using these cost figures the urethane system chemical costs, per repair by pipe size is:

6-inch	$5.30	15-inch	$13.55
8-inch	7.30	18-inch	16.05
10-inch	8.95	21-inch	19.00
12-inch	10.75	24-inch	21.50

The additional cost of the new sealants at $3.12 to $21.50 per repair compared with the average acrylamid gel cost of $6.00 per repair (which could range from $2.00 to $12.00 per repair) is of very little consequence when compared with the job quality obtainable. It is also of little consequence since the chemical cost per repair is less than 10 percent of the cost of the total repair.

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No. 915,961, "Asphaltic Sealing & Coating Compositions," 1963.

No.1,083,490, "Seam Sealer for Plastic Parts."

No. 947,586, "Polyurethane Pipe-Joint Adhesive," 1964.

No. 885,762, "Consolidating the Surface of Permeable Mineral Material," Appl. 1960.

No. 1,009,198, "Sealing & Lining Compositions."

No. 1,021,715, "Bitumen-Rubber Joint-Sealing Compositions."

No. 921,046, "Organosiloxane Resin Compositions Curable at Room Temperature," 1963.

5. Belguim Patents

No. 612,784, "Polyurethanes Modified with Polyethylene," 1962.

No. 609,212, "Sealing Compound for Anaerobic Vulcanization Having Great Storage Stability," 1962.

6. Netherlands Patents

No. 6,407,641, "Materials Curing with Exclusion of Air for Use as Sealant & Adhesive," 1965.

No. 6,609,969, "Hardenable Composition and Shaped Articles Therefrom."

7. Russian Patents

No. 187,595, "Water Impermeable Cements or Mortars," 1966.

No. 127,347, "Luting Cement," 1960.

No. 141,623, "Polymers," 1961.

8. Polish Patents

No. 50,088, "Sealing Putty."

SECTION VII.

GLOSSARY AND ABBREVIATIONS

Amine value - the number of milligrams of KOH equigalent to the base content of one gram of fatty polyamide as determined by titration with HCl.

DGEBA - Diglycedyl ether of bisphonol A.

DGEPG - Diglycidyl ether or propylene glycol.

Epoxy equivalent weight - the weight of resin in grams which contains one gram equivalent of epoxy.

phr - parts per hundred parts by weight.

ppm - part per million.

Thixotropy - the property which enables a system to exhibit a time-dependent reversible and isothermal decrease of viscosity with sheer in flow.

T. I. - thixotropic index = $\frac{\text{Viscosity at 2 rpm}}{\text{Viscosity at 20 rpm}}$.

W. P. E. - weight per equivalent; same as epoxy equivalent weight.

APPENDICES

APPENDIX I

CHEMICAL SUPPLIERS

ADM Chemicals, Division
Ashland Oil and Refining Co.
Minneapolis, Minn.

A & S Corporation
Verona, N.J.

Abacus Polymer, Inc.
Skokie, Ill.

Acco Polymers
Brooklyn, N.Y.

Adhesive Engineering Co.
San Carlos, Calif.

Airco Chemicals & Plastics
New York, N.Y.

Alcolac Chemical Corp.
Baltimore, Md.

Allied Chemical Corp.
Morristown, N.J.

American Chemical Corp.
Long Beach, Calif.

American Polymers, Inc.
Paterson, N.J.

American Resin Corp.
Chicago, Ill.

Applied Plastics Co., Inc.
El Segundo, Calif.

Armstrong Products Co., Inc.
Warsaw, Ind.

Atlas Minerals & Chemicals Div.,
The Electric Storage Battery Co.
Mertztown, Pa.

Axel Plastics Research Lab., Inc.
Long Island City, N.Y.

Baker Castor Oil Co.
Bayonne, N.J.

Borden Chemical Co., Division
The Borden Co.
New York, N.Y.

Brand Plastics Co.
Chicago, Ill.

CIBA Products Co., Division
CIBA Corp.
Summit, N.J.

C P R Division,
The Upjohn Company
Torrance, California

Cadillac Plastic Co., Division
Dayco Corp.
Detroit, Mich.

Cardinal Chemical Co.
Columbia, S.C.

Catalin Corp., Division
Ashland Oil and Refining Co.
New York, N.Y.

Celanese Coatings Co.,
Resins and Chemicals Division
Louisville, Ky.

Chemical Coatings & Engineering
Co., Inc.
Media, Pa.

Chemical Industries
Pasadena, Calif.

Chevron Chemical Co.
San Francisco, Calif.

Columbian Carbon Co.,
Plastics Division
New York, N.Y.

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Commercial Resins Division,
Interplastic Corp.
Minneapolis, Minn.

Commercial Solvents Corp.
New York, N.Y.

Conap, Inc.
Allegany, N.Y.

Cook Paint and Varnish Co.
Kansas City, Mo.

Cosden Oil & Chemical Co., Sub.
American Petrofina, Inc.
New York, N.Y.

Diamond Alkali Co.
Cleveland, Ohio

Dolph, John C., Co.
Monmouth Junction, N.J.

Dow Chemical Co.
Midland, Mich.

DuPont de Nemours, E.I.,
& Co., Inc.
Wilmington, Del.

Durez Division,
Hooker Chemical Corp.
Tonawanda, N.Y.

East Coast Chemicals Co.
Little Falls, N.J.

Eastman Chemical Products, Inc.,
Sub. Eastman Kodak Co.
Kingsport, Tenn.

El Monte Chemical Co.
Pasadena, Calif.

Epoxylite Corp.
El Monte, Calif.

Eronel Industries
Hawthorne, Calif.

Escambia Chemical Corp.
New York, N.Y.

Ethyl Corp.
New York, N.Y.

Ethyl Corp.,
Polymers Division
Baton Rouge, La.

FMC Corp.,
Organic Chemicals Division
New York, N.Y.

Fenwal, Inc.
Ashland, Mass.

Fiberfil Division,
Rexall Chemical Co.
Evansville, Ind.

Firestone Plastics Co., Division
Firestone Tire & Rubber Co.
Pottstown, Pa.

Firestone Rubber & Latex Products
Fall River, Mass.

Fisher Melamine Corp., Division
Ashland Oil & Refining Co.
New York, N.Y.

Foster Grant Co., Inc.
Leominster, Mass.

France Campbell & Darling, Inc.
Kenilworth, N.J.

Freeman Chemical Corp., Division
H.H. Robertson Co.
Port Washington, Wis.

Furane Plastics, Inc.
Los Angeles, Calif.

Future Chemicals Group of Mfg. Cos.
Chicago, Ill.

General Electric Co.,
Chemical Materials Dept.
Pittsfield, Mass.

General Electric Co.,
Insulating Materials Dept.
Schenectady, N.Y.

General Foam Plastics Corp.
Portsmouth, Va.

General Latex & Chemical Corp.
Cambridge, Mass.

General Mills, Inc.,
Chemical Division
Kankakee, Ill.

George, P.D., Co.
St. Louis, Mo.

Georgia-Pacific Corp.,
Resins Department
Portland, Ore.

Goodrich, B.F., Chemical Co.
Cleveland, Ohio

Goodyear Tire & Rubber Co.,
Chemical Division
Akron, Ohio

Great American Plastics Co.
Fitchburg, Mass.

Hammond Plastics, Inc.
Worcester, Mass.

Harwick Standard Chemical Co.
Akron, Ohio

Hastings Plastics, Inc.
Santa Monica, Calif.

Hercules Incorporated
Wilmington, Del.

Hightemp Resins, Inc.
Stamford, Conn.

Houdry Process & Chemical Co.,
Division Air Products & Chemicals
Philadelphia, Pa.

Interchemical Corp.,
Finishes Division
Detroit, Mich.

International Coatings Co., Inc.
Compton, Calif.

Ironsides Resins, Inc.
Columbus, Ohio

Isochem Resins Co.
Lincoln, R.I.

Isocyanate Products, Inc.
New Castle, Del.

Kaiser Aluminum & Chemical Corp.
Oakland, Calif.

Key Polymer Corp.
Lawrence, Mass.

Klenk Chemical Corp.
Detroit, Mich.

Koppers Co., Inc.,
Tar & Chemical Division
Pittsburgh, Pa.

Lakeside Plastics Corp.
Oshkosh, Wis.

Leepoxy Plastics, Inc.
Fort Wayne, Ind.

M&T Chemicals, Inc.
Rahway, N.J.

Marblette Corp.
Long Island City, N.Y.

Marbon Chemical Division,
Borg-Warner Corp.
Washington, W.Va.

Marco Chemical Division,
W.R. Grace & Co.
Linden, N.J.

Metachem Resins Corp.,
Mereco Products Corp. Div.
Cranston, R.I.

Miller-Stephenson Chemical Co., Inc.
Danbury, Conn.

Millmaster Onyx Corp.
New York, N.Y.

Mobay Chemical Co.
Pittsburgh, Pa.

Mobil Chemical Co.,
Plastics Division
Macedon, N.Y.

Mol-Rez Division,
American Petrochemical Corp.
Minneapolis, Minn.

Monsanto Co.
St. Louis, Mo.

Morton Chemical Co.
Chicago, Ill.

O.C. Adhesives Corp.
Brooklyn, N.Y.

Olin Mathieson Chemical Corp.,
Organic & Specialty Chemicals Div.
New York, N.Y.

Omni Division,
C. Tennant, Sons & Co. of
New York
New York, N.Y.

Osborn, C.J., Co.
Linden, N.J.

PPG Industries/Coatings &
Resins Division
Pittsburg, Pa.

Pacific Resins & Chemicals, Inc.
Seattle, Wash.

Pelron Corp.
Lyons, Ill.

Pennsalt Chemicals Corp.
Philadelphia, Pa.

Pennsylvania Industrial Chemical
Clairton, Pa.

Phelan's Resins & Plastics, Div.
Phelan-Faust Paint Mfg. Co.
Burlington, Iowa

Phillips Petroleum Co.,
Chemical Dept.
Bartlesville, Okla.

Plastic Engineering & Chemical Co.
Fort Lauderdale, Fla.

Poly Resins
Sun Valley, Calif.

Polyrez Co., Inc.
Woodbury, N.J.

Polyurethane Products Co., Inc.
St. Louis, Mo.

Polyvinyl Chemicals, Inc.
Wilmington, Mass.

Polyurthan Division,
Easton R S Corp.
Brooklyn, N.Y.

Purethane Division,
Easton R S Corp.
Brooklyn, N.Y.

Quaker Oats Co.,
Chemicals Division
Chicago, Ill.

Reichhold Chemicals, Inc.
White Plains, N.Y.

Research Sales, Inc.
Suffern, N.Y.

Rezolin, Inc.
Santa Monica, Calif.

Richardson Co.
Polymers Division
West Haven, Conn.

Ridgway Color & Chemical Co.,
Division Martin Marietta Corp.
Ridgway, Pa.

Rohm & Haas Co.
Philadelphia, Pa.

Rubba, Inc.
Bronx, N.Y.

Ruca Division
Hooker Chemical Corp.
Hicksville, N.Y.

Sartomer Resins, Inc.
Essington, Pa.

Schenectady Chemicals, Inc.
Schenectady, N.Y.

Sealzit Division
Flintkote Co.
Riverside, Calif.

Shanco Plastics & Chemicals, Inc.
Tonawanda, N.Y.

Shell Chemical Co.,
Industrial Chemicals Div.
New York, N.Y.

Sherwin-Williams Co.,
Pigment, Color & Chemical Dept.
Cleveland, Ohio

Silmar Division,
Vistron Corporation
Hawthorne, California

Sinclair-Koppers Co.
Pittsburg, Pa.

Sinclair Petrochemicals, Inc.
New York, N.Y.

Spencer Kellogg Division,
Textron Inc.
Buffalo, N.Y.

Stauffer Chemical Co.,
Plastics Division
New York, N.Y.

Sterling Varnish Co.
Sewickley, Pa.

Sun Chemical Corp.
Chemical Products Division
Doylestown, Pa.

Synco Resins, ADM chemicals,
Archer Daniels Midland Co.
Bethel, Conn.

Synvar Corp.
Wilmington, Del.

Techform Laboratories, Inc.
Venice, Calif.

Tenneco Chemicals, Inc.
Tenneco Plastics Division
Piscataway, N.J.

Thiokol Chemical Corp.
Chemical Division
Trenton, N.J.

Tra-Con, Inc.
Medford, Mass.

Tylac Chemicals, Division
International Latex & Chemical
Dover, Del.

Union Carbide Corp.
Chemicals & Plastics Div.
New York, N.Y.

Uniroyal, Inc.
Adhesives & Coatings Department
Mishawaka, Ind.

Uniroyal, Inc.
Uniroyal Plastic Products
Chicago, Ill.

United States Gypsum Co.
Chicago, Ill.

U.S. Industrial Chemicals Co., Div.
National Distillers & Chemical
New York, N.Y.

Upjohn Co.,
Polymer Chemicals Div.
Kalamazoo, Mich.

Valite, Division
Valentine Sugars, Inc.
New Orleans, La.

Valspar Industrial Div.
Lyons, Ill.

Vanderbilt, R.T., Co.
New York, N.Y.

Wilson & Co., Inc.
Wilson-Martin Division
Philadelphia, Pa.

Witco Chemical Co., Inc.
New York, N.Y.

Wyandotte Chemicals Corp.,
Industrial Chemicals Group
Wyandotte, Mich.

APPENDIX II

CERAMIC, CLAY AND CONCRETE TILE CORRELATION

Two groups of data were established to determine the relationship of ceramic tile (1/4-inch thick) to clay tile (3/4-inch thick) when used as substrates for testing strengths of various adhesive materials. First, eight bonds were made with epoxy, using only ceramic tiles. Then eight identical bonds were made, using only clay tile. Similar sets of data were generated by using polyurethane as the adhesive.

These data were analyzed for correlation of the variance in the following manner:

$$r = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}}{\sqrt{\left[\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right]\left[\Sigma Y^2 - \frac{(\Sigma Y)^2}{n}\right]}}$$

where r = correlation coefficient.

Results:

1. Epoxy.

1/4-inch ceramic tile (X) and 3/4-inch clay tile (Y)

X	Y	
304	482	$n = 8$
330	507	$\Sigma Y = 5102$
376	510	$\bar{Y} = 637.7$ (avg.)
471	661	$\Sigma X = 4043$
495	666	$\bar{X} = 505.3$ (avg.)
593	725	$\Sigma X^2 = 2,254,745$
677	729	$\Sigma Y^2 = 3,362,700$
797	822	$\Sigma XY = 2,725,191$
		$r = .97$

Clay tile bondings by epoxy averaged 25.5 percent higher strength than ceramic tile bondings.

2. Polyurethane.

1/4-inch ceramic tile (X) and 3/4-inch clay tile (Y)

X	Y	
102	62	$n = 8$
114	81	$\Sigma Y = 993$
116	104	$\bar{Y} = 124$ (avg.)
129	111	$\Sigma X = 1143$
140	142	$\bar{X} = 143$ (avg.)
144	157	$\Sigma X^2 = 173,037$
178	165	$\Sigma Y^2 = 13,882$
200	171	$\Sigma XY = 151,299$
		$r = .77$

Ceramic tile bondings by polyurethane averaged 15.8 percent higher strength than clay tile bonding.

Attempts were made to test sealants on concrete tiles made by the following formula:

1000 gms Portland cement
400 gms sand
400 gms water

These tiles were cured for from two to three weeks at room temperature, then tested with the materials listed in Table II. Most failures occurred within the cement, and the cement blocks were regarded as having insufficient strength to effectively test the high-strength bonding materials. An average of all data (noted by "3-failure within the cement," Table XI), yields the following:

Tensile strength -- 199 psi (low of 155, high of 237).
Flexural strength -- 666 psi (low of 410, high of 984).

It may be concluded that testing of any material showing sufficient adhesion and demonstrating the strengths listed above would result in failure of the concrete rather than within the tested material.

TABLE XI. Results of Testing of Cement Blocks.

Material	Tensile	Type Failure	Flexural	Type Failure
Escoweld 7502	237	3	410	3
Escoweld 7505	206	3	442	3
Matstick No. 24 and No. 25	219	3	736	3
Matstick No. 26 and No. 27	202	3	684	3
Scotchweld 2216	204	3	831	3
NuKlad No. 105	177	3	661	3
Baker System No. 65	159	1	622	1
Cital 2805 (T)	155	3	664	3
Trabond 2143	198	3	756	3
Trabond 2133	235	3	599	3
Araldite 6005 and 508	208	3	494	3
Selectron RS-5119	155	3	157	1
U.C. 8698	196	3	733	3
Urabond 836-S	118	1	428	1
Syncore 600 and A-1-37	104	2	133	1
W.S. Dickey DCUE 1072-31	117	1	289	1
H 705	69	2	105	1
A205	61	2	140	1
Derakane 411-45	194	3	984	3

Type failure 1 = Failure within the adhesive.
2 = Failure at the interface between sealant and cement.
3 = Failure within the cement.

A. Initial Screening Tests of Sealant Candidates.

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength		Flexural Strength		Modulus of Elasticity		Remarks
						Dry (psi)	Wet (psi)	Dry (psi)	Wet (psi)	Dry (psi)	Wet (psi)	
M6354	Synthetic Elastomer	U.S. Rubber Co.	Thixotropic	16 hours	0.59	41	0	0	0	0	0	Affected by water.
Pioneer 301 (Summer Grade)	Plastic Bituminous Sealer	Witco Chemical Co.	Paste	Remains soft	0.45 to 0.50	0	0	-	-	-	-	Did not run flexural test because of tensile values.
Pioneer 301 (Winter Grade)	Plastic Bituminous Sealer	Witco Chemical Co.	Paste	Remains soft	0.45 to 0.50	0	0	-	-	-	-	Same as Summer Grade.
Exon 470	Vinyl Chloride Copolymer	Firestone	210 cps	Solvent evaporation	0.48	39	0	0	0	0	0	Affected by water.
Megaplug	-	Oil Center Research	1 cp	15 minutes	-	0	0	-	-	-	-	Did not run flexural test because of tensile values.
Conap DP-2351B	Urethane	Conap Inc.	Paste	5 to 7 days moisture core	20.00 /qt.	24	41	0	0	0	0	Very long cure time.
Witmer No. 86	Thermoset-ting Elas-tomer	Witco Chemical Co.	900 cps	≤ 24 hours	0.37	72	0	0	0	0	0	Affected by water.
Epoxy Adhesive 907	Epoxy	Miller-Stephenson Chemical Co.	Thixotropic	24 hours	1.60 /kit	2,396	1,074	5,386	4,727	2.48×10^6	1.51×10^5	No flexibility.
Isopox No. 661	Epoxy/Rub-ber Base	Adhesive Products	Paste	≤ 4 hours	0.85	271	25	0	0	0	0	Poor adhesion, affected by water.
Pond Sealant 14MR	Catiosonic Asphaltic Emulsion	Pennsalt Chemical Corp.	80 cps	Does not cure	0.75 /gal	0	-	-	-	-	-	Is not an adhesive sealant, more like a grout.
Tra-Bond 2116	Epoxy	Tra-Con Inc	Thixotropic	16 hours	25.00 /gal	1,135	702	3,570	3,120	2.29×10^6	2.34×10^6	Expensive and water affected tensile strength.
Eastobond No. 7682 -19	Poly Olefin	Eastman Chemical	2,900 cps	Does not cure. Hot-melt	0.15	0	0	-	-	-	-	No adhesive strength.
Eastobond No. 7682-17	Poly Olefin	Eastman Chemical	Paste	Does not cure. Hot-melt	0.18	2	0	0	0	0	0	No adhesive strength

A. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Eastobond No. 7682-13	Poly Olefin	Eastman Chemical	Paste	Does not cure. Hot melt	0.16	8	0	0	0	0	0	No adhesive strength.
Araldite 509	Epoxy	Ciba Products	500-700 cps	≤18 hours	0.555	904	764	1,562	453	3.66×10^6	3.27×10^5	Affected by water.
Fast-Fix 40%	Gypsum Cement	Western Company	3,760 cps	≤2 hours	0.333	327	0	253	0	1.32×10^5	-	Affected by water.
Spenkel M90-80X	Urethane	Spencer-Kellogg	1,800 cps	24 hours	0.52	143	0	121	0	6.15×10^3	-	Affected by water.
QX3923	Vinyl Ester Resin	Dow Chemical	- - - - - - -	- - - - - - -	- - - -	Was	replaced by	Durak	ane 41	1-45-	- - - - - - -	- - - - - - -
Byeriyte No. 635	Asphalt Petroleum Solvents and Fibers	Byerlyte Co. Div. of Koppers and Co.	Paste	Does not cure.	5.50	0	12	-	-	-	-	Similar to Pioneer 301
Nu Klad No. 110	Epoxy Based	Amercoat Corp.	Thixotropic	≤4 hours	23.90	42	154	40	41	8.79×10^2	8.87×10^3	Very flexible.
AM-9 Grout	Acrylosuid Gel	American Cyanamid	1 cp	3 to 5 minutes	1.05	0	-	-	-	-	-	No strength used as a grout.
Cital 2805	Epoxy Based	Citrey Corp.	5,450 cps	set in 4 to 5 hours	15.65	836	972	2,041	2,518	5.67×10^6	1.79×10^6	2805 thixotrope has greater strength.
Polymer No. 63-7501-0	Atactic Polypropylene	Paisley Products	Dependent on solvent concentration	Air cure 24 hours	0.20	0	0	0	0	0	0	No strength.
Fast-Fix W.P.	Gypsum Cement	Western Company	4,800 cps	Set in ≤ 30 minutes	0.05	73	23	579	40	1.14×10^6	-	Affected by water.
Nu Klad No. 165	Epoxy Based	Amercost Corporation	850	≤18 hours	0.467	816	753	2,702	2,319	6.12×10^6	1.04×10^7	3-component system.
XC6-203	Epoxy	Ren Plastics	13,000 cps	6 hours, tack-free	186./gal	778	930	2,187	1,909	1.16×10^6	2.07×10^6	Epoxy seems brittle.

A. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Urabond 835	Urethane	Poly Resins	Thixotropic	48-96 hours	0.58	81	4	82	0	1.24×10^3	-	Water affected bond between adhesive and tile.
Selectron RS-5119	Polyester	Pittsburgh Plate Glass	650 cps	1 hour	0.23	288	321	1,191	972	4.12×10^5	1.75×10^6	---
Escourield 7502	Epoxy	Enjay Chemical	a)900 cps b)5000cps	24 hours	1.50	1,151	1,156	2,112	1,780	1.95×10^6	-	---
Trabond 2143D	Epoxy	Tra-Con Inc	a)39000cps b)48000cps	18 hours	25.00 /gal	1,296	1,122	3,411	2,801	7.64×10^6	2.16×10^6	Expensive.
Trabond 2133	Epoxy	Tra-Con Inc	2,200 cps	18 hours	2.31	1,159	781	2,553	1,872	4.72×10^6	3.02×10^6	Expensive.
Urabond 836	Urethane	Poly Resins	Thixotropic	48-96 hours	0.61	33	165	0	32	0	8.1×10^1	Did not bond well to tile.
Urabond 835-S	Urethane	Poly Resins	30-60 poises	48-96 hours	0.61	96	95	41	0	1.45×10^3	0	Did not bond well to tile.
Urabond 836-S	Urethane	Poly Resins	50-100 poises	48-96 hours	0.61	103	125	78	209	1.41×10^3	1.59×10^2	Good bonding to tile.
Araldite 6005 and 508	Epoxy	Ciba Products	a)9500 cps b)2000-5000 cps	18 hours	0.555 0.715	975	577	1,486	937	2.24×10^5	4.00×10^5	Component epoxy system.
Syncore 600 and A-1-37	Polyester Urethane	Synvar Corporation	2,600 cps	1 hour	0.26 0.36	428	68	416	81	5.35×10^3	6.87×10^3	Flexible and foams.
Thiokol H 705	Polysulfide	Thiokol Chemical	500 poises	Set in 24 hours	0.84	45	47	81	41	1.26×10^3	9.38×10^2	Very flexible.

A. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Thiokol A205	Polysulfide	Thiokol Chemical	500 poises	3 hours	0.915	36	42	41	41	1.02 x 10^3	6.77 x 10^3	Very flexible.
Syncore 24-P-100 and A-1-37	Polyester Urethane	Synvar Corporation	4000 cps	30 minutes	-	353	8	722	42	1.04 x 10^6	4.55 x 10^3	Bond affected by water.
Durez 16470	Furfuryl Alcohol Resin	Hooker Chemical	200 cps	18 hours in small quantities	0.322	81	40	73	177	3.01 x 10^4	3.69 x 10^6	Hard to cure, mass critical.
NuKlad No. 105 Primer	Epoxy Based	Amercoat Corp.	Resin280cps CA 400 cps	24 hours	1.51	406	229	657	104	1.77 x 10^5	1.31 x 10^5	Slow curing, with good flexibility.
Esccweld 7505	Epoxy	Enjay Chemical	1100-1300 cps(blended)	24 hours	1.59	876	733	1,728	1,190	4.23 x 10^6	1.25 x 10^6	Low viscosity.
Baker Castor Oil System No. 65	Ricinoleate Urethane	Baker Castor Oil Co.	400 poises	7 days	0.79 0.65	174	58	67	0	1.54 x 10^3	-	Very high viscosity. Slow cure.
U.C. 8698	Epoxy	Pittsburgh Plate Glass	Paste	3 hours	9.50	1,165	1,502	4,969	4,492	8.93 x 10^6	2.21 x 10^7	Very good strength. Good resistance to water.
Cital 2805 Thixotrope	Epoxy	Citrey Corp.	Thixotropic	Set in 4-5 hours	15.65	1,136	752	3,373	2,017	2.02 x 10^6	1.22 x 10^6	Expensive, good bonding.
Matstick No 26 and 27	Epoxy Polysulfide	Matcote Company	Putty	72 hours	1.43	430	664	573	1,753	5.27 x 10^4	9.65 x 10^6	Slow curing and high viscosity.
Scotch-weld 2216	Epoxy	3-M	a)80000cps b)100000cps	24 hours	24.45	805	1,531	3,816	3,573	2.26 x 10^5	1.97 x 10^5	Experience and slow curing.

A. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Matstick No. 24 and 25	Epoxy Polyenide	Matcote Company	Thixotropic	18 hours	1.55	1,694	848	5,549	3,971	1.87×10^6	1.35×10^6	Strong adhesion.
WEP 26	Water Extended Polyester	Ashland Chemical Company	2,750 cps 55%water	Gel in 7 minutes	0.32	17	-	20	-	9.4×10^3	-	Coating polyester. Not suitable.
WEP 42	Water Extended Polyester	Ashland Chemical Company	500 cps 55%water	Gel in 6 minutes	0.21	2	-	0	-	0	-	Coating polyester. Not suitable
WEP 21	Water Extended Polyester	Ashland Chemical Company	12,750cps 75%water	Gel in 25 minutes	-	6	-	0	-	0	-	Coating polyester. Not suitable.
WEP 27	Water Extended Polyester	Ashland Chemical Company	1,400 cps 55%water	Gel in 6 minutes	0.21	23	-	21	-	9.3×10^3	-	Slightly better adhesive properties than other WEP.
Laminac 126-3	Polyester	American Cyanamide	880 cps	1 hour	-	275	2	425	59	3.82×10^5	2.8×10^4	Cannot be used by itself, never fully cures.
Derahave 411-45	Vinyl Ester Resin	Dow Chemical	500 cps	Gel in 12 minutes	-	897	858	2,045	1,927	7.3×10^5	1.33×10^6	Good strength.

B. Performance of Sealants on Sewage Soaked Tiles.

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Flexural Strength Dry (psi)	Modulus of Elasticity Dry (psi)
Escoweld 7502	Epoxy	Enjay Chemical	a)900cps b)5000cps	24 hours	1.59	> 1,164	2,700	1.04×10^7
Tra Bond 2143	Epoxy	Tra-Con Inc.	a)39000cps b)48000cps	18 hours	25.00	> 1,158	2,403	1.73×10^6
Tra Bond 2133	Epoxy	Tra-Con Inc	2200 cps	18 hours	2.31	> 1,154	2,493	1.75×10^6
Urabond 836-S	Urethane	Poly Resins	50-100poises	48-96 hours	0.61	194	179	1.86×10^3
Araldite 6005 and 508	Epoxy	Ciba Products Company	a)9500 cps b)2000-50000 cps	18 hours	0.555 0.715	> 1,094	2,257	1.41×10^6
Syncore 600 and A-1-37	Polyester Urethane	Synvar Corporation	(blended) 2600 cps	1 hour	0.26 0.36	144	0	0
Thiokol H705	Poly-sulfide	Thiokol Chemical	500 poises	24 hours	0.84	42	0	0
Thiokol A205	Poly-sulfide	Thiokol Chemical	500 poises	3 hours	0.915	14	40	5.92×10^2
Durez 16470	Furfuryl Alcohol Resin	Hooker Chemical	200 cps	18 hours in small quantities	0.322	125	99	4.54×10^3
NuKlad No. 105 Primer	Epoxy Based	Amercoat Corporation	a)200 cps b)400 cps	24 hours	1.51	898	729	3.09×10^5
Escoweld 7505	Epoxy	Enjay Chemical	1100-1300 cps(blended)	24 hours	1.59	870	2,134	2.48×10^6

B. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure T[illegible]	Cost ($/lb)	Tensile Strength Dry (psi)	Flexural Strength Dry (psi)	Mudulus of Elasticity Dry (psi)
Baker Castor Oil System No. 65	Ricinoleate Urethane	Baker Castor Oil Company	400 poise	7 days	0.79 0.65	174	0	0
U.C. 8698	Epoxy	Pittsburgh Plate Glass	Paste	3 hours	9.50 /gal	$>$1,154	4,232	2.05×10^6
Cital 2805 Thixotrope	Epoxy	Critex Corporation	Thixotropic	Set in 4-5 hours	15.65	$>$1,165	3,215	1.19×10^6
Matstick No. 26 and 27	Epoxy Polysulfide	Matcote Company	Putty	72 hours	1.43	573	916	2.75×10^5
Scotch-Weld 2216	Epoxy	3-M	a)80000cps b)100000cps	24 hours	24.43 /gal	982	2,146	6.35×10^5
Matstick No. 24 and 25	Epoxy Polyamide	Matcote Company	Thixotropic	$<$18 hours	1.55	1,075	3,113	5.27×10^6
Derakane 411-45	Vinyl Ester Resin	Dow Chemical	500 cps	Gel in 12 minutes	-	381	1,648	1.56×10^5
DCUE-1072-31	Urethane	W.S. Dickey Clay Mfg.	4000 cps	$<$30 minutes	0.50	346	573	1.53×10^4
Selectron RS-5119	Polyester	Pittsburgh Plate Glass	650 cps	1 hour	0.23	96	584	2.73×10^5

C. Affects of Silanes.

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Selectron RS-5119	Polyester	Pittsburgh Plate Glass	650 cps	1 hour	0.23	288	321	1,191	972	4.12 x 10^5	1.75 x 10^6	Room temperature curing polyester.
						-	608	-	1,914	-	8.3 x 10^5	Tile pretreated with A186 (Epoxy-terminated).
						-	483	-	1,534	-	5.6 x 10^5	Tile pretreated with A187 (Epoxy-terminated).
			CabosilM-5 Thixotropic			615	354	1,754	1,966	1.39 x 10^6	1.52 x 10^6	Tile not pretreated.
						-	626	-	2,784	-	6.73 x 10^5	Tile pretreated with A186.
						-	1,052	-	2,301	-	1.12 x 10^7	Tile pretreated with A187.
Tra-Bond 2133	Epoxy	Tra-ConInc	2200 cps	18 hours	2.31	1,159	781	2,553	1,872	4.72 x 10^6	3.02 x 10^6	Tile not pretreated.
				50 minutes		-	>1,166	-	2,606	-	7.1 x 10^5	DMP-30 accelerator.
						-	>1,167	-	3,816	-	1.39 x 10^6	Tile pretreated with A186. DMP-30 accelerator. Tile pretreated with A187.
Syncore 600 and A-1-37	Polyester Urethane	Synvar Corporation	2600 cps	1 hour	0.26 0.36	428	68	416	81	5.35 x 10^3	6.87 x 10^3	Flexible and foams.
						-	217	-	192	-	7.89 x 10^3	Tile pretreated with W.S. Dickey DC 5010.
Syncore 24-P-100 and A-1-37	Polyester Urethane	Synvar Corporation	4000 cps	30 minutes	-	353	8	722	42	1.04 x 10^5	4.55 x 10^3	Bond affected by water.
						-	180	-	163	-	5.54 x 10^3	Tile pretreated with W.S. Dickey DC 5010.

C. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexible Strength Dry (psi)	Flexible Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
NuKlad No. 105 Primer	Epoxy Based	Amercoat Corporation	Resin-280 cps C.A.-400 cps	24 hours	1.51	406	229	657	104	1.77 x 10^5	1.31 x 10^5	Slow curing, but good flexibility.
				1-1/2hours		-	628	-	2,288	-	1.11 x 10^6	Tile pretreated with A186. DMP 30 accelerator.
						-	>1,168	-	3,194	-	1.23 x 10^6	Tile pretreated with A186 DMP 30 accelerator.
Escoweld 7505	Epoxy	Enjay Chemical	1100-1300 cps (blended)	24 hours	1.59	876	733	1,728	1,190	4.23 x 10^6	1.25 x 10^6	Low viscosity.
						-	515	-	1,404	-	7.75 x 10^5	Tile pretreated with A186.
						-	690	-	2,246	-	1.84 x 10^6	Tile pretreated with A187.
Baker Castor Oil System No. 65	Ricinoleate Urethane	Baker Castor Oil Company	400 poises	7 days	Vorite-0.79	174	58	67	0	1.54 x 10^3	0	Very high viscosity, slow curing.
				2 hours	Polycin 0.65	208	120	-	-	-	-	A1100 added to urethane system to improve adhesion. Stannous octoate as an accelerator.
WEP 27	Water Extended Polyester	Ashland Chemical	1400cps 55%water	Gel in 6 minutes	0.21	23	-	21	-	9.3 x 10^3	-	Poor adhesion properties.
						563	512	1,922	2,413	6.77 x 10^5	9.61 x 10^5	Tile pretreated with A174 (0.1%).
						94	110	-	-	-	-	Tile pretreated with A172 (0.1%) and dried at 110°C for 3 hours before applying WEP.
						655	545	-	-	-	-	Same as above, using A174 instead of A172.
						99	139	-	-	-	-	Same as above, using A186 instead of A172.
						156	119	-	-	-	-	Same as above, using A187 instead of A172.

C. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Kerakane 411-45	Vinyl Ester Resin	Dow Chemical	500 cps	Gel in 12 minutes	-	897	858	2,045	1,927	7.3 x 10^5	1.33 x 10^6	Good strength.
						-	960	-	3,819	-	6.39 x 10^6	Tile pretreated with A174 (0.1%).
						-	769	-	2,193	-	5.75 x 10^6	A174 added to resin system (0.2%).
						-	674	-	1,309	-	2.52 x 10^6	Tile pretreated with A187 (0.1%).
						-	909	-	2,068	-	2.44 x 10^6	A187 added to resin system (0.2%).
W.S. Dickey DCUE-1072-31	Urethane	W.S. Dickey Clay Mfg.	4000 cps	< 30 minutes	0.50	93	2	63	0	4.84 x 10^3	0	Good flexibility, fair to poor bonding.
						352	136	317	132	1.07 x 10^4	2.75 x 10^3	Tile pretreated with DC 5010.
W.S. Dickey B 430	Urethane	W.S.Dickey Clay Mfg.	1000cps	< 30 minutes	-	286	-	141	-	6.92 x 10^3	-	Lower viscosity than DCUE-1072-31, same base material.
						292	98	389	142	2.60 x 10^4	1.61 x 10^4	Tile pretreated with DC 5010.
Epon 828 with Phenyl glycidyl Ether	Epoxy	Shell Chemical	Used Cabosil M-5 Thixotropic	1 hour, 40 minutes	-	-	>1,140	-	3,600	-	6.50 x 10^6	Tile untreated. C.A.- Araldite No. 956.
						-	>1,144	-	4,954	-	6.32 x 10^6	Tile pretreated with A186. C.A.- Araldite No.956.
						-	>1,165	-	5,074	-	6.80 x 10^6	Tile pretreated with A187. C.A.- Araldite No. 956.

C. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Epon 828 with Butyl Glycidyl Ether	Epoxy	Shell Chemical	Used Cabosil M-5 Thixotropic	40 minutes	-	-	>1,143	-	5,014	-	1.12 x 10^7	Tile untreated. C.A. - Araldite 956.
						-	>1,143	-	5,192	-	6.4 x 10^6	Tile pretreated with A186. C.A. - Araldite No. 956.
						-	>1,134	-	5,860	-	1.01 x 10^7	Tile pretreated with A187. C.A. - Araldite No. 956.
						>1,182	>1,207	5,768	6,341	2.58 x 10^7	1.72 x 10^7	A1100 blended in epoxy system (1.0%). C.A. - Araldite No. 956.
Epon 828 with Dectyl Glycidyl Ether	Epoxy	Shell Chemical	Used Cabosil M-5 Thixotropic	50 minutes	-	-	>1,136	-	5,749	-	8.08 x 10^6	Tile untreated. C.A. - Araldite No. 956.
						-	>1,141	-	5,022	-	8.75 x 10^6	Tile pretreated with A186. C.A. - Araldite No. 956.
						-	>1,140	-	6,079	-	4.79 x 10^6	Tile pretreated with A187. C.A. - Araldite No. 956.
Epon 828 and LP 3	Epoxy Polysulfide	Shell Chemical Thiokol Chemical	Thixotropic	30 minutes	-	781	1,141	1,186	2,081	1.05 x 10^5	2.48 x 10^5	50% epoxy, 50% polysulfide. C.A. - Araldite No. 956. (20 pks of epoxy) Tile pretreated with A187.
						1,099	620	1,984	1,545	2.7 x 10^5	2.59 x 10^5	Same as above, except tile pretreated with XZ-8-5411A
Epon 828 and LP 3	Epoxy Polysulfide	Shell Chemical Thiokol Chemical	Thixotropic	30 minutes	-	1,108	>1,138	1,866	3,081	3.63 x 10^5	6.15 x 10^5	50%epoxy, 50% polysulfide. C.A. - Araldite No. 956. pks epoxy). Tile pretreated with A187.
						830	801	1,809	1,443	1.74 x 10^5	2.40 x 10^5	Same as above, except tile pretreated with XZ-8-5114A

C. (Continued)

Union Carbide Products

A-151	vinyltricoxysilane
A-172	vinyl-tris (2-methoxyethoxy) silane
A-174	gamma-methacryloxypropyltrimethoxysilane
A-186	beta-(3,4-epoxycyclohexyl) ethyltrimethoxysilane
A-187	gamma glycidoxypropyltrimethoxysilane
A-1100	gamma-aminopropyltriethoxysilane

Dow Corning Products

C-600	
X2-8-5,14	70% solution in methanol of a mercaptosilane salt

D. Effects of Various Curing Agents and Reactive Diluents.

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Epon 828 with Butyl glycidyl ether	Epoxy	Shell Chemical	880 cps	1 hour, 20	-	710	-	1,714	-	5.8 × 10^5	-	C.A. - Araldite No. 955
				3 hours, 10 minutes		229	-	107	-	5.0 × 10^4	-	C.A. - Lutrizol CA 23.
				1 hour, 5 minutes		259	-	41	-	4.0 × 10^4	-	C.A.-Triethylenetetramine
				1 hour, 30 minutes		317	-	917	-	1.01 × 10^5	-	C.A.-Tetraethylene-pentamine.
				55 minutes		135	-	107	-	1.96 × 10^5	-	C.A.-Diethylenetriamine.
				35 minutes		-	-	398	-	7.36 × 10^5	-	C.A.-Araldite No. 963.
				40 minutes		>1,165	984	2,274	2,216	2.17 × 10^6	1.91 × 10^6	C.A.-Araldite No. 956.
Epon 828 with Phenyl glycidyl ether	Epoxy	Shell Chemical	1040 cps	3 hours	-	685	-	846	-	9.50 × 10^5	-	C.A.-Triethylenetetramine.
				3 hours, 15 minutes		227	-	1,257	-	1.61 × 10^6	-	C.A.-Tetraethylene-pentamine.
				40 minutes		328	-	0	-	0	-	C.A.-Diethylenetriamine.
				1 hour, 40 minutes		1,077	1,097	5,370	2,735	4.11 × 10^6	3.48 × 10^6	C.A.-Araldite No. 956.
Epon 828 with Alhyl glycidyl Ether	Epoxy	Shell Chemical	1120 cps	2 hours, 30 minutes	-	577	-	1,371	-	3.9 × 10^5	-	C.A.-Araldite No. 955.
				1 hour, 40 minutes		191	-	2,210	-	8.84 × 10^6	-	C.A.-Triethylenetetramine.
				1 hour, 5 minutes		303	-	246	-	3.85 × 10^5	-	C.A.-Tetraethylene-pentamine.
				1 hour, 45 minutes	-	259	-	526	-	3.85 × 10^5	-	C.A.-Diethylenetriamine.
				35 minutes		68	-	298	-	2.90 × 10^5	-	C.A.-Araldite No. 963.
				1 hour, 35 minutes		1,145	588	2,667	2,011	4.36 × 10^6	2.65 × 10^6	C.A.-Araldite No. 956.

D. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Cost ($/lb)	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Epon 828 with Dectyl glycidyl ether	Epoxy	Shell Chemical	1120 cps	3 hours, 30 minutes	-	281	-	547	-	1.25×10^5	-	C.A.-Lubrizol C.A.
				1 hour		267	-	82	-	1.0×10^5	-	C.A.-Triethylenetetramine.
				1 hour, 15 minutes		644	-	-	-	-	-	C.A.-Tetraethylenepentamine. Sample did not fully cure for flex.
				1 hour		119	-	503	-	6.26×10^5	-	C.A.-Diethylenetriamine.
				50 minutes		>1,142	852	2,006	1,784	7.71×10^6	1.91×10^6	C.A.-Araldite No. 956
Epon 828	Epoxy	Shell Chemical	16000cps	1 hour, 15 minutes	-	>1,166	-	2,694	-	1.43×10^6	-	C.A.-Araldite No. 955.
				1 hour, 15 minutes		>1,175	-	2,951	-	1.15×10^6	-	C.A.-Lubrizol C.A.
				1 hour		>1,168	-	2,579	-	6.27×10^6	-	C.A.-Triethylenetetramine.
				35 minutes		994	-	3,439	-	6.54×10^6	-	C.A.-Tetraethylenepentamine
				30 minutes		>1,161	-	1,496	-	6.73×10^5	-	C.A.-Diethylenetriamine.
				30 minutes		589	-	1,598	-	2.58×10^5	-	C.A.-Araldite No. 963.
				1 hour, 30 minutes		1,043	-	3,444	-	4.24×10^5	-	C.A.-Araldite No. 956.

E. Polysulfide System Used With Various Curing Agents.

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Epon 828/LP 3	Epoxy Polysulfide	Shell Thiokol	Thixotropic	15 minutes	>1,146	>1,155	2,742	3,279	1.16 x 10^5	1.25 x 10^5	50% epoxy, 50% polysulfide. C.A.-Diethylenetriamine. Tile pretreated with A187. 10-phr epoxy.
					933	971	1,170	2,264	5.33 x 10^5	6.97 x 10^5	Same as above. C.A.-Tetraethylenepentamine (10-phr epoxy).
					333	0	245	0	2.72 x 10^4	0	Same as above. C.A.-Tetraethylenepentamine (20-phr epoxy).
					1,115	1,061	2,367	3,593	6.77 x 10^5	1.04 x 10^6	Same as above. C.A.-Triethylenetetramine (10-phr epoxy).
					914	846	1,363	1,940	1.72 x 10^5	1.64 x 10^5	Same as above. C.A.-Triethylenetetramine (20-phr epoxy).
				30 minutes	397	878	357	1,570	7.55 x 10^4	2.55 x 10^5	Same as above. C.A.-Araldite No. 956 (10-phr epoxy).
					781	1,144	1,186	2,081	1.05 x 10^5	2.48 x 10^5	Same as above. C.A.-Araldite No. 956 (20-phr epoxy).
Epon 828/LP 33	Epoxy Polusulfide	Shell Thiokol	Thixotropic	15 minutes	>1,151	>1,149	2,880	2,810	7.36 x 10^5	4.90 x 10^5	50% epoxy, 50% polysulfide. C.A-Diethylenetriamine (10-phr epoxy). Tile pretreated with A 187.
					536	562	698	450	6.59 x 10^4	5.36 x 10^4	Same as above. C.A.-Diethylenetriamine (20-phr epoxy).
				30 minutes	668	1,142	743	2,696	1.31 x 10^5	5.19 x 10^5	Same as above. C.A.-Tetraethylenepentamine (10-phr epoxy).
				20 minutes	>1,141	>1,136	1,735	4,182	9.71 x 10^5	1.48 x 10^6	Same as above. C.A.-Tetraethylenepentamine (20-phr epoxy).

E. (Continued)

Name of Compound	Type	Source	Viscosity	Set Time or Cure Time	Tensile Strength Dry (psi)	Tensile Strength Wet (psi)	Flexural Strength Dry (psi)	Flexural Strength Wet (psi)	Modulus of Elasticity Dry (psi)	Modulus of Elasticity Wet (psi)	Remarks
Epon 828/LP 33	Epoxy Polysulfide	Shell Thiokol	Thixotropic	30 minutes	>1,186	>1,141	3,266	3,478	7.45 x 10^5	6.64 x 10^5	50% epoxy, 50% polysulfide C.A.-Triethylenetetramine (10-phr epoxy).
				20 minutes	959	926	1,985	1,259	2.52 x 10^5	1.72 x 10^5	Same as above. C.A.-Triethylene-tetramine (20-phr epoxy).
				30 minutes	232	581	259	817	2.70 x 10^5	1.07 x 10^5	Same as above. C.A.-Araldite No. 956 (10-phr epoxy).
				40 minutes	1,108	1,138	1,866	3,082	3.63 x 10^5	6.13 x 10^5	Same as above. C.A.-Araldite No. 956 (20-phr epoxy).

LP-3 = low viscosity polysulfide
LP-33 = differs from LP-3 in percent crosslink and percent mercaptan.
Produced by Thiokol Chemical.

F. Resistance to Sewage Tests.						
		Before Soaking		After Soaking		
Name of Compound	Type	Weight (gm)	Volume (cc)	Weight (gm)	Volume (cc)	Comments
Selectron RS-549	Polyester	100.46	83	100.62	80	Slight discoloration, probably due to absorbance of H_2O.
U. C. 8698	Epoxy	32.89	28	33.05	27	No apparent change
Urabond 836-S	Urethane	39.80	28	40.31	32	No apparent change
W. S. Dickey Urethane	Urethane	18.81	15	19.84	17	No apparent change
Thiokol No. 705	Epoxy polysulfide	52.28	28	51.86	37	No apparent change
Thiokol No. 205	Epoxy polysulfide	49.38	39	49.25	38	No apparent change
Durakane 411-45	Vinyl ester resin	64.31	57	64.41	59	Discoloration, probably due to absorbance of H_2O
Escoweld 7502	Epoxy polyamide	35.17	31	35.78	33	Discoloration, probably due to absorbance of H_2O
Escoweld 7505	Epoxy polyamide	37.97	36	38.18	32	No apparent change
Matstick No. 24 and No. 25	Epoxy polyamide	38.17	32	39.85	32	No apparent change
Matstick No. 26 and No. 27	Epoxy polysulfide	34.26	25	34.56	27	Pale yellow color

F. (Continued)

Name of Compound	Type	Before Soaking		After Soaking		Comments
		Weight (gm)	Volume (cc)	Weight (gm)	Volume (cc)	
Scotchweld 2166	Epoxy	24.58	19	24.96	18	No apparent change
NuKlad No. 105	Epoxy-based primer	48.36	40	48.70	40	No apparent change
Cital 2805 (T)	Epoxy coating	25.58	15	25.70	13	No apparent change
Tru-Bond 2143	Epoxy polyamide	32.80	28	33.74	33	No apparent change
Baker System 63	Urethane	39.12	44	39.21	47	Floats. No apparent change.
Tru-Bond 2133	Epoxy polysulfide	41.57	36	41.96	32	No apparent change
Araldite 6005 and 508	Epoxy	44.96	40	46.58	40	Discoloration due to absorbance of H_2O
Durez 16470	Turfuryl alcohol resin	37.12	30	37.10	29	No apparent change.

APPENDIX IV

PRELIMINARY ESTIMATES OF THE PROPERTIES OF GROUTING MATERIALS *

Material	Properties										Remarks
STEEL MICROSIL											
CEMENT Portland Arkansaite											
ASPHALT Portland Arkansaite											
CLAY Portland Arkansaite											
ACCESSORY Portland Arkansaite											

NOTE: [illegible]

* [illegible]

* [illegible]

END